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A SIMULATION ANALYSIS OF THE USAF
COMMISSARY CUSTOMER SERVICE
ENVIRONMENT IN SUPPORT OF AFCOMS
STORE-LEVEL STAFF SIZING

THESIS

Bruce H. Fritz II
Captain, USAF

AFIT/GOR/ENS/84D-4

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STORE-LEVEL STAFF SIZING

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

Bruce H. Fritz II
Captain, USAF

April 1991

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Preface

The objective of this research was twofold: (1) To determine the probable impact of the proposed Air Force Commissary Service Manpower Standard for Customer Service upon the commissary operations environment; and (2) To investigate the sensitivity of performance parameters within the customer service system. This was accomplished by means of a computer simulation model together with data collected from commissaries located at Lackland Air Force Base in Texas and Rhein Main Air Base in West Germany.

I wish to acknowledge those people that have provided guidance and assistance in preparing this thesis. First, a word of thanks to my advisors, Colonel Thomas F. Schuppe and Major Joseph R. Litko for their help and patience throughout this arduous process. I would also like to thank those people at the Air Force Commissary Service who provided advice and data - Ken Jones, Mel Palmer, Richard Juarez, William Saffeeles, Melba Verna, Capts Rick Britt and Mike Stark. I'd like to thank Lt Col Stan Polk and Dr. Manuel Pina for providing me with a challenging problem and the opportunity to tackle it. The research staff of the Human Resources Laboratory Technical Library at Brooks AFB also deserves recognition for their tireless assistance. But most important, I would like to express my deepest gratitude to my wife, Sarah, for her assistance and support during the completion of this project. Her insight and selfless efforts were vital elements throughout this endeavor. She was always there when I needed her help. Thank you.

Bruce H. Fritz II

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Abstract

The purpose of this research was to determine the probable impact of the proposed Air Force Commissary Service (AFCOMS) Manpower Standard for Customer Service (Manpower Standard) upon the commissary operating environment and to investigate the sensitivity of performance parameters within the customer service system. The specific research problems addressed were:

- 1) A comparison of the cashier manpower requirements calculated by the proposed AFCOMS Manpower Standard to those determined by a simulation model under similar conditions
- 2) Calculation of the expected mean and maximum waiting times in the commissary environment given the proposed Manpower Standard
- 3) Determination of the sensitivity of customer waiting time performance measures to variations in arrival patterns and service rates and to queueing system configuration

A SLAM-based simulation model (MGPCSS) was used for this analysis as the primary means to conduct the research. The model was used to produce a series of runs within an experimental design which bounded the normal operating conditions in the commissaries under study. This information was used to develop a regression model which calculated cashier hours based upon customer service system operations parameters. The regression model was then used to check the proposed Manpower Standard and determine the effect, if any, its implementation would have on the customer service environment in Air Force commissaries. The results of the research indicated that the implementation of the Manpower Standard would create a situation in which waiting times would increase slightly. Other

environmental factors such as queueing configuration, average service time, and managerial control level will affect the overall impact of the new standard, but simulation analysis clearly showed a tendency for the waiting time parameters to increase while the cashier utilization rates changed very little. Due to restrictions on the composition of the Manpower Standard linear model (no negative or second-order terms), this standard will not likely improve customer waiting conditions in the commissary.

**A SIMULATION ANALYSIS OF THE USAF COMMISSARY
CUSTOMER SERVICE ENVIRONMENT IN SUPPORT OF
AFCOMS STORE-LEVEL STAFF SIZING**

1. Introduction

Background

Historically, surveys of Air Force families have consistently ranked the commissary entitlement as the most important available military benefit second only to the provision of health care. (1) Commissary patrons worldwide generate \$8.8 million in sales every day, making the Air Force Commissary Service (AFCOMS) the fourteenth largest food retailing organization in the U.S. (1) Because the operation of Air Force commissaries is not profit-oriented as is a commercial grocery chain, AFCOMS chooses to prioritize customer service in its global operation of 148 retail locations. (2:7) Consequently, AFCOMS management is interested in efforts to minimize the time customers must wait in checkout lines. But because available manpower is a limited resource, store managers must schedule checkout personnel so as to balance customer waiting time considerations while maintaining a high degree of worker utilization. As Thomas J. Frey described it in his study of server scheduling:

Somewhere, between long and short lines, an ideal exists. Keeping the line length and the corresponding customer waiting time at this ideal is difficult, especially in the face of limited total monthly checker-hours. (12:1)

Effective scheduling is a very challenging task primarily due to the uncertainty in predicting customer arrival patterns. As a

result, much greater emphasis is being placed upon the use of analytical tools to provide credible guidance for this type of problem. According to Baker, "... in service-oriented industries, where labour is a very significant input factor, the trend towards greater use of mathematical models is reflected in the design and implementation of sophisticated manpower scheduling systems." (5:155)

In 1987, AFCOMS conducted a Functional Review of Commissary Customer Service operations (hereafter called the "Functional Review") in order to revise the current manpower requirements "standard" which provides the fundamental authority for the determination of individual store personnel allocations. This Functional Review was performed in accordance with Air Force Regulation (AFR) 25-5 which provides the official administrative guidelines for an effort of this type. The result of this effort was the AFCOMS Manpower Standard for Customer Service, hereafter referred to as the "Manpower Standard." Development of the Manpower Standard required a work sampling collection effort to document the operational relationships between customer arrival rates, cashier utilization, and available levels of manpower through observed system behavior. In conjunction with this, historical commissary operations data was collected to augment the work sampling effort. This approach reflected the guidance provided in AFR 25-5 which states, "Normally, standards are built through the use of detailed work measurement methods and statistical analysis of historical data." (4:1-1,2) The

accumulated data was loaded into a statistical analysis package to develop a linear regression equation which would represent the new AFCOMS Manpower Standard. More detail concerning the development of the Manpower Standard is found in Chapter IV. Appendix F contains a short summary of the regression analysis which developed the revised Manpower Standard.

The systematic approach used in the Functional Review analysis involved the characterization of a non-linear process (the commissary customer service environment) by a linear model (the Manpower Standard regression equation). While this presents no analytical weakness, senior AFCOMS management is very interested in any proposed changes to store operations with such high customer visibility. Customer surveys conducted by AFCOMS consistently indicate "long waiting lines" to be the single most-often cited complaint of patrons. In addition, modifying the manpower authorizations for the customer service departments command-wide is always a very sensitive issue for all levels of AFCOMS administration. As a result, AFCOMS was interested in developing an alternative methodology to verify the proposed Manpower Standard as an appropriate update for the customer service system. This effort proposes the use of simulation modeling as a means to analyze the new Manpower Standard prior to implementation. The use of a logical, well-constructed simulation model provides an independent means to test the dynamics of the changing environment and increase confidence in the proposed Manpower Standard model.

HQ AFCOMS currently has a simulation model which can be used

for this analysis - the General Purpose Commissary Store Simulation (GPCSS). The original model is discussed in Chapter II and the updated model (MGPCSS) used in the analysis is described in Chapter IV.

Specific Question

The Air Force Commissary Service Manpower Standard for Customer Service is being revised. How will the new standard impact the performance of the customer service system at the store level?

Research Objectives

The purpose of this effort is twofold: (1) To determine the probable impact of the proposed Manpower Standard upon the customer service environment; and (2) To determine the sensitivity of the customer service system performance measures to changes in the primary factors which dictate manpower requirements at the store level. Both objectives will be achieved through the use of a simulation model.

Specific Problems

The specific problems for this research will be addressed by performing the following tasks:

- 1) Compare the cashier requirements determined by the AFCONS Manpower Standard for a given store with those calculated by the simulation model under similar conditions.

2) Determine the expected mean and maximum waiting times for AFCOMS patrons for a given store using the proposed Manpower Standard.

3) Determine the sensitivity of customer waiting time performance measures to changes in customer arrival patterns and variations in service rates and to queueing system configuration.

Scope and Limitations

The Functional Review was concerned with establishing appropriate manning requirements for the entire customer service system to include checkout personnel, access-control personnel, and the cash-control staff. This analysis is strictly concerned with the checkout personnel within the system and only those duties directly related to customer processing functions. Other duties, which include cash-cage transaction processing and "unshopping" (replacing unsold items on store shelves), are disregarded. As such, adjustments to the Functional Review data collection were necessary to ensure the comparisons between the Manpower Standard model and the simulation model were valid. These adjustments are described in more detail in Chapter IV. In addition, customer coupon redemption has proven to be a significant driver for commissary cashier labor requirements. However, coupon-redemption data for the Functional Review data collection time period (April 1987 - March 1988) was unavailable. Coupon data from the May-June 1989 time frame was available for Lackland AFB. As a result, some of the basic assumptions for coupon use during the Functional Review data collection effort were derived from this data. More detail concerning these assumptions is highlighted in Chapter IV.

Finally, the study was limited to a pair of stores - Lackland AFB, Texas and Rhein Main AB in West Germany. These particular stores were chosen to represent a large-sized store and a small-sized store as well as a cross-section of other factors as well. Time has limited this effort to a small subset of the available store profiles. However, this thesis will demonstrate an analysis methodology which can be applied to other stores of interest.

Plan of the Report

Chapter I outlined the introduction to the research task. It includes the background of the problem, the specific question posed, the research objectives of the effort, subsidiary problems, and the scope and limitations of the research. Chapter II is a Review of the Literature to include historical research regarding queueing analysis, previous commissary operations analysis, and a discussion of issues concerning the use of simulation in modeling efforts. Chapter III describes the research methodology employed for this effort. Chapter IV details the development of the AFCOMS linear regression model for the customer service system (Manpower Standard), discusses the modifications made to the simulation model, and debates the issues which impact the validation of the modified simulation model. Chapter V details the organization of the analysis methodology. Chapter VI describes the results of the analysis and discusses each of the posed research problems. Chapter VII summarizes the conclusions and recommendations of the research.

II. Review of the Literature

This review of the literature will focus upon four primary areas of interest: 1) Fundamental concepts in the field of queueing theory which provide a cornerstone for understanding the dynamics of the service environment; 2) Historical queueing-system applications research; 3) Previous research which addresses USAF commissary-related operations questions; and 4) Issues which examine the role of simulation as an analysis tool.

Queueing Theory

The history of the field of operations research analysis can trace much of its initial growth to the study of queueing concepts and basic systems. But while many of the richest contributions to the study of queueing systems include the general models and algorithms developed during the infancy of the discipline, much of the recent literature devoted to queueing analysis has focused upon specific scenarios and application techniques. This review will emphasize the underlying principles of queueing analysis and a few selected applications rather than providing an exhasutive listing of recently published research. Concepts which will be examined include what a "queue" is; the required parameters to describe a queue; the traditional variations of these queue parameters; and the performance evaluation of a queue. Following this introductory section, a selected group of queueing system studies will be explored which provide further insight into the problems being addressed in this study.

BASIC CONCEPTS

Saaty (31) provides an excellent overview of the roots of queueing study as well as a foundation in the principles of fundamental queueing concepts and applications. Saaty defines a "queue" simply as "... a waiting line." It "involves arriving items that wait to be served at the facility which provides the service they seek." (31:3) Common examples which we encounter every day include waiting for a traffic light to change, waiting to cash a check at the credit union, or waiting in line to buy groceries at the commissary.

In order to fully describe a queue, three basic structures must be specified: 1) the arrival pattern - both the rate of arrival and the pattern of the arrivals (probability distribution); 2) the service mechanism - this includes when service is available, how many customers may be serviced at one time, and how long the service will take; and 3) the queue-discipline - the means by which a customer is selected for service from the waiting area. Common methods include FIFO (First-In First-Out) and LIFO (Last-In First-Out). (14:4) The system capacity must also be indicated if the queue size is restricted due to a systematic limitation (e.g. floor space). The queue description should also include any interaction between the parts of the system if such interactions exist. (9:4) A basic notational system to represent queueing conditions was created by D. G. Kendall and is used throughout the field. The queueing process is represented by a series of symbols and slashes where the symbols indicate the parameters of the process and the

slashes separate the symbols into distinct fields. An example of this notation would be $A/B/X/Y/Z$. A represents the interarrival-time distribution; B is the probability distribution of the service time; X is the number of parallel service channels; Y is the restriction on system capacity; and Z is the queue discipline. Table 1 summarizes the various options for each of the queue parameters. (14:8-10) Table 1 is not intended to be an exhaustive list of all possible configurations, but it lists those types most commonly found in queueing study literature.

Table 1. Queueing Parameters (14:9)

Characteristic	Symbol	Explanations
Interarrival-time distribution (A)	M	Exponential
	D	Deterministic
	E_k	Erlang type k (k=1,2,...)
	GI	General Independent
Service-time distribution (B)	M	Exponential
	D	Deterministic
	E_k	Erlang type k (k=1,2,...)
	G	General
Number of parallel servers (X)	1,2,... ∞	
Restriction on system capacity (Y)	1,2,... ∞	
Queue discipline (Z)	FIFO	First-In First-Out
	LIFO	Last-In First-Out
	SIRO	Service In Random Order
	PRI	Priority
	GD	General Discipline

Most of the parameter variations listed in Table 1 need no explanation. However, the E_k , G, & GI options require further definition. The G and GI alternatives indicate "general" probability distributions; no assumption is made regarding the precise definition of the distribution. (14:10) As Gross describes:

General Independent requires that interarrival times be independent & identically distributed random variables. General service also requires that service times be independent as well as identically distributed, but the convention developed by Kendall dropped the word independent when referring to service, probably to allow more freedom in notation and not to force the same letter(s) to be used twice. (14:10)

E_k is used to represent a distribution known as the "type k Erlang." It is more precisely defined as a gamma distribution with an integral number of degrees of freedom. (14:10)

This examination of basic queueing theory should also include an introduction to some of the interesting phenomena associated with customer behavior which are common to most conventional queueing systems, including those found in USAF commissaries. These phenomena include: 1) Balking, 2) Jockeying, 3) Reneging, and 4) Collusion.

"Balking" is defined as customer refusal to enter the queue upon arrival. (14:3) In the commissary environment, the customer may become discouraged after observing the current service conditions and decide to seek service later or at a different location. "Jockeying" is described as moving from one service line to another in a queueing system with two or more parallel service

lines. (14:3) This is a very common event in many service facilities where service times are not constant and one service line will often move faster than another. Occasionally, new lines are opened for business and people waiting in existing lines see an opportunity to shorten their expected wait. Each of these two phenomena will occur in the commissary environment and are represented in the modeling effort of this thesis. Chapter IV will describe how the simulation model incorporates balking and jockeying into the flow of commissary operations.

"Reneging" is a queueing event defined as an impatient customer leaving the service queue without being serviced. (14:3) The expected wait for service may exceed the willingness of the customer to remain in the service facility, causing the customer to depart prematurely. This event seems to be quite uncommon in USAF commissaries. "Collusion" is an event defined as the cooperation of two or more customers in which one customer waits in line for the group while the others are free to perform any desired shopping. (31:10) This practice is generally "frowned-upon" and is often unofficially prohibited in AFCOMS stores. Since neither of these events is very common in the commissary environment, they were not incorporated into the simulation model used for the analysis.

The final aspects of traditional queueing theory to be examined are the conventions normally affiliated with system performance measures. As Gross wrote:

Generally there are three system responses of interest. These are (1) some measure of the waiting time that a customer might be forced to endure; (2) an indication of the manner in which customers may accumulate; and (3) a measure of the idle time of the servers. Since most queueing systems have stochastic elements, these measures are often random variables and their probability distributions, or at the very least their expected values, are desired to be found. (14:8)

Within these response measure classes, there are specific measures of effectiveness (MOEs) which are suitable for this systematic evaluation. Average customer waiting time and maximum customer waiting time are both appropriate response MOEs. Customer accumulation can be measured for both multiple service-line and single service-line environments. For server utilization, the proportion of busy/idle man-hours and total man-hours processed are adequate measures. For very sophisticated, complex systems, other measures may be of interest. Multiple-level queueing systems in particular present complex situations where simple measurement criteria may not be suitable. Additional material regarding more sophisticated queueing environments is available in Gross (14), Cox (9), and Saaty (31).

QUEUEING SYSTEM APPLICATIONS

Queueing analysis is not solely confined to quantitative assessments. Studies have also focused upon the qualitative aspects of queueing systems. Jones (18) did a short study of consumer acceptance of changing queueing conditions in the grocery store business. The study investigated the prevailing attitudes of grocery store patrons concerning the preferred service environment

of the store. To gather data for the study, a telephone survey was conducted in which household members were polled about their knowledge of single-line service systems, what their shopping habits were concerning stores, and how they would change their shopping habits if a store they shopped at implemented a single-line service system. The responses indicated that a significant portion of the consumers who are "loyal" to a particular store would patronize a different store if the alternative (single-line) system were implemented. This was thought to be the result of two primary factors: 1) "...consumers' 'perception' of the time spent rather than the 'actual' time spent in line to obtain the needed service. Consumers may perceive that lines in grocery stores move faster than those in bank and postal systems;" (18:92) and 2) The personal relationships that patrons may have developed with individual cashiers would be intruded upon by instituting a single-line queueing system where the patron would be unable to choose their cashier. These observations were consistent with a study by Stone which revealed the concept of four shopper "types." They include the "economic" shopper, the "apathetic" shopper, the "ethical" shopper, and the "personalizing" shopper. (18:91) The data indicated that economic and apathetic shoppers would be most receptive to the alternative service system because these consumer types are most concerned with monetary savings, and efficient task completion, respectively. Intuitively, the typical military commissary patron would likely be an economic shopper. After all, the characteristic of the military commissary which makes it an

attractive and useful benefit for its patrons is the monetary savings advantage it provides authorized patrons. Personal interaction will not be as important to this consumer as saving money. Negative perceptions of "unusual" service conditions would likely impact less upon this type of shopper since the primary objective of the economic shopper is to maximize his or her food dollar. Thus, the single-line service system should be the logical choice for implementation in virtually all commissary store configurations. Only those stores where some physical constraint would limit the effectiveness of a single-line queueing discipline should consider alternative systems.

Weisselberg and Cowley (35) examined queueing systems from the perspective of reducing the system to its basic components and then examining those components by asking a series of questions to determine if any of the components might be changed such that the overall service throughput rate would improve. For the commissary system, adding another phase of processing to more efficiently handle coupon transactions might be a possible candidate. But the cost of additional technology plus the reaction of present customers might indicate that any likely improvement in service might not be worthwhile at the present time. Streamlining a service system is rarely a trivial task. However, the effort to look for improvements can sometimes yield sizeable bonanzas in system efficiency. As the authors point out, "... a slight cut in service time can bring dramatic improvement, particularly when

arrivals are random." (35:32) But they add a note of caution for wanton changes with "... speeding up service, if it means a decline in quality or a pace that cannot be maintained, can only be a temporary solution." (35:32)

They next examined the arrival function of the queueing system through a different set of questions in an effort to determine if any adjustments to this portion of the system would also yield improvement. However, most systems will have little or no control over the customer arrival pattern and will rarely be capable of altering the arrival function in a manner which would improve the queueing process while not adversely impacting the customer base. Changing or expanding hours of operation, for example, is one way in which to alter the arrival function for a given queueing system. But changing hours may prove inconvenient to present customers, and simply expanding the hours of operation may prove to be too costly.

The authors discuss the variation in both arrival rate and in service rate which will often occur when the size of the waiting line changes. Intuitively, a person is much more likely to wait for a haircut in a barber shop if only one or two people are waiting ahead of him than if five or six customers are already waiting. As discussed in the Basic Concepts, this "likelihood to leave" represents the system "balk" rate. With respect to the service function, many productivity studies have indicated that the system service rate will often steadily increase up to a given point as the waiting line increases. Workers tend to work faster if they can see tasks waiting for their attention. However, this

tendency can negatively impact the system in a fashion akin to the previous concern about a possible decrease in the quality of service coinciding with an increase in the service rate. (35)

Next, the authors presented an example to illustrate the practical use of the questions previously discussed in searching for simple solutions to waiting-line problems. The workload for a single order-taker was investigated to determine more efficient ways to conduct business in a timely, effective manner. Finally, after many alternative strategies were employed as the level of business increased, a point was reached where additional labor was necessary to properly handle the greater workload. (35)

This essay illustrated how simple alternative strategies should first be examined as possible solutions before employing expensive, time-consuming modifications to the present system (e.g. additional personnel). However, business growth (a likely goal for almost any firm including AFCOMS) will ultimately require either a larger staff or advanced technology to properly handle the higher activity requirements.

A second application involved a 1972 study by students at the University of Oklahoma School of Industrial Engineering. Their analysis focused on a local bank which was preparing to expand their drive-in facilities and was considering "robot" teller stations to augment their conventional teller stations. (11) Because expansion space was at a premium, the "robot" stations were being considered because they required less area and could be

installed in greater numbers than normal teller stations. In addition, the bank was very concerned with their level of customer service and how it might be affected by the facility expansion.

The problem was defined to be a comparison of one system having five normal drive-in teller stations with a system having three normal teller stations and two "robot" tellers. Customer waiting time was devised as the primary measure of effectiveness while installation costs were considered only as a backup criterion (11:31). After data collection was completed, and probability distributions determined for the arrival and service functions, the students began to formulate the analysis methodology. A bank policy of customers waiting no longer than four minutes was incorporated into the problem. The service process was broken down into a series of events to determine what proportion of a given transaction involved teller action. Queueing system formulas were used to calculate expected waiting times and the statistical distribution for waiting times. (11:33)

The study results indicated that the "robot" tellers would be the preferred method of expansion and that the current system was capable of handling the increased workload without compromising customer service. A follow-up analysis summary indicated that the "robot" tellers were added to the drive-in facility as suggested and the new system functioned as predicted (except for a period of customer "conditioning.") Some customers were uncomfortable with the robotic teller stations and would often bypass them at the expense of their own time. But once the "robophobia" had worn off,

the new drive-in system functioned very smoothly. (11:36)

This case study was a good example of how queueing theory can be applied to the "real" world and provide accurate information to decision-makers interested in changing or expanding their organizational capabilities.

Whitt (36) conducted a study which looked at the concept of "choosing a queue to join." Most of us routinely choose the "shortest" queue when all other known factors are equal, but Whitt argues that this is not always the most optimal choice.

The system model was specified as a two server, one-queue-per-server system with queues of infinite capacity. The arrival function was assumed to be Poisson (for simplicity), but the service time function was defined as a distribution with probability $1-x$ for $\text{time} = 0$ and probability x for $\text{time} = n$ when x is a small value. The decision maker knows only the lengths of each queue. The basic queue discipline is one of First-come-first-served (FCFS). One example of such a system might be a toll collection point on an interstate highway with only two active booths.

Whitt argues that his decision algorithm, the "dominating alternative decision rule," is superior to the "shortest-line rule" for this particular model when the difference in queue length between the two lines is two or more. The two rules are the same when either of the queues are empty or the length difference is zero or one. The basic premise of Whitt's decision rule is that

the shorter queue may indicate a recent service completion and that the next service completion is more likely to occur at the server with the longer queue. And the profile of the service-time probability distribution would indicate more service completions at the same server in a very short period of time. Obviously, the service-time probability distribution, which in this case "captures the essence of a distribution with a U-shaped failure rate," (36:57) is the fundamental force behind this decision algorithm developed by Whitt.

Whitt goes on to discuss another decision rule called the "shortest-expected-delay" rule, in which customers "join the queue that will minimize their individual expected delays." (36:59) The application of this decision algorithm is dependent on knowing how long the customers in service have been in service.

This application, while many of its assumptions will not normally occur in a commissary-like environment, offers an intriguing example of counter-intuitive decision-making. Customers using a service facility which has characteristics similar to the ones profiled by Whitt might find themselves often frustrated by the apparent "misbehavior" of a system which they thought they understood. Unusual systems such as this one provide more insight into queueing environment understanding and help to unlock our approach to common problems by suggesting uncommon solutions.

This concludes the review of basic queueing system concepts and selected queueing system applications. The next section

addresses previous research in the military commissary operations environment.

Commissary Operations

There have been several research efforts in the past few years which have specifically addressed a variety of commissary operations applications.

Stark (33) investigated the performances of two alternative inventory control procedures selected from current literature and compared them with the strategy currently employed by AFCOMS. This was done to determine if the current procedure being used by AFCOMS were really the best choice. (33:vii)

First, two alternative reorder strategies were selected from current inventory management theory literature. Next, performance measures were developed to be able to rigorously compare the three different systems on a consistent basis. These performance measures were primarily concerned with the level of customer service (not-in-stock rate) vice dollar value of average inventory levels. In addition, assumptions were made regarding the demand functions for the set of line items to be used in the analysis. This was quite critical as the choice of probability distribution would largely determine which reorder system would be most useful. (33:viii)

The analysis was accomplished through the use of a simulation model written in SLAM (see Chapter IV) with a cross-section of items carried in the typical USAF commissary. The results of the

study indicated that one of the alternative strategies chosen for comparison was the most effective strategy for inventory reorder.

This study was useful to this effort from the standpoint that it used actual AFCOMS data regarding inventory processing and revealed important characteristics about the way AFCOMS conducts business.

Britt (7) also explored inventory control policy procedures with the goal of developing a set of regression equations to optimize the distribution of inventory dollars among a group of competing grocery line items.

A simulation model was used to generate a response surface for each of the different inventory review period values in the AFCOMS data. The response surface equations were used to create an "Inventory Availability Model" (IAM) which optimized system-level line item availability as measured by marginal analysis. The IAM was also used to create a "shopping list" of line items whose priorities are determined by their contribution to the availability measure. (7:71)

The general result of this study was that inventory items with characteristics which produced "unstable" stock levels would appear closer to the top of the "shopping list." (7:71) This effort was most useful as a source of regression analysis and its application to simulation model output.

In addition, there have been three recent efforts which

specifically examined the USAF Commissary customer service environment. Dorough and Holliway used simulation modeling to compare the system performance of different queueing configurations within the Wright-Patterson AFB commissary. (10) Their research indicated that the single service-line queueing configuration is the logical choice to minimize customer waiting times in the commissary operations environment. (10:72) This finding was consistent with similar studies which have examined checkout facilities for other environments comparable to the commissary system.

Frey (12) developed an analytical model to schedule commissary cashiers such that "the expected customer waiting-time would remain relatively constant throughout the scheduling period." (12:vi) It was a two-phase model in which the initial phase used dynamic programming to determine the optimal number of cashiers required throughout the day in order to satisfy the desired customer waiting-time goal. To accomplish this, a fluid-approximation of the service-queue length was used for the calculation of the average customer waiting time during each time interval. The second phase of the model implemented a shift-scheduling constraint through integer programming to determine the necessary number of cashiers for each shift assignment such that the Phase-One requirements were satisfied. A third phase of the scheduling process in which actual employees are assigned to the resultant shift-schedule was not addressed in this effort. The checker

scheduling model was validated using a simulation model developed for this effort by Frey. The results of this validation indicated that the scheduling program was effective until nearing day end. At this point, the accuracy of the program deteriorated. To compensate for this, cashiers were added heuristically during this phase of operation to maintain the desired customer waiting time goal. (12:55)

Finally, a commissary operations simulation model called the General Purpose Commissary Store Simulation (GPCSS) was developed by Captain Roger Moulder in 1987. It was intended "to provide AFCOMS with an analytic tool to aid in managing Air Force commissaries." (26:vii) GPCSS is a store-level end-to-end simulated operations model. It was originally designed to assist commissary store managers with customer service decision-making as well as provide an analysis tool to HQ AFCOMS operations analysts interested in exploring alternative service configurations. The model was intended to support AFCOMS in its dual role as follows:

First, it was to provide an easy-to-use, user-friendly system for the individual store managers to experiment with their customer-service configuration without having to make actual physical changes to the store. This would allow the manager to investigate the impact the proposed changes would have on the service environment without risk. For example, the manager might wish to see how the system would react to changing the service scheme from the present double-line service-queue to a single-line

service-queue. Or, he might be interested in allocating another checkout station for express service and wishes to find out how that would affect the overall system. GPCSS was intended to provide a quick and simple answer to these types of questions.

The other application the model was designed to support was as an analysis tool for HQ AFCCMS operations analysts. It was supposed to allow the staff analyst to vary the statistical parameters within the model to determine the sensitivity of the service environment performance. For example, the analyst may be assigned the task of studying the impact of increasing the number of items which an express customer is permitted to buy during a single transaction. Or interest might develop in finding out how long customers wait in line during peak business periods in a given store. GPCSS was designed to provide the mechanism to be able to answer questions of this nature.

GPCSS is structured as a seven-part process which follows the patron from parking-lot arrival to departure. That process is as follows: (1) Secure a parking place (if one is available); (2) pass through the entry-control checkpoint; (3) stamp a check (if patron is paying by check); (4) obtain a shopping cart (large for full-service, small for express-service); (5) shop for desired items; (6) join a checkout service-queue; and (7) depart from the commissary parking lot (making the vacated parking place available to another patron). Figure 1 illustrates this process.

Basic data required for input includes the number of available parking slots, the number of large and small shopping carts, the

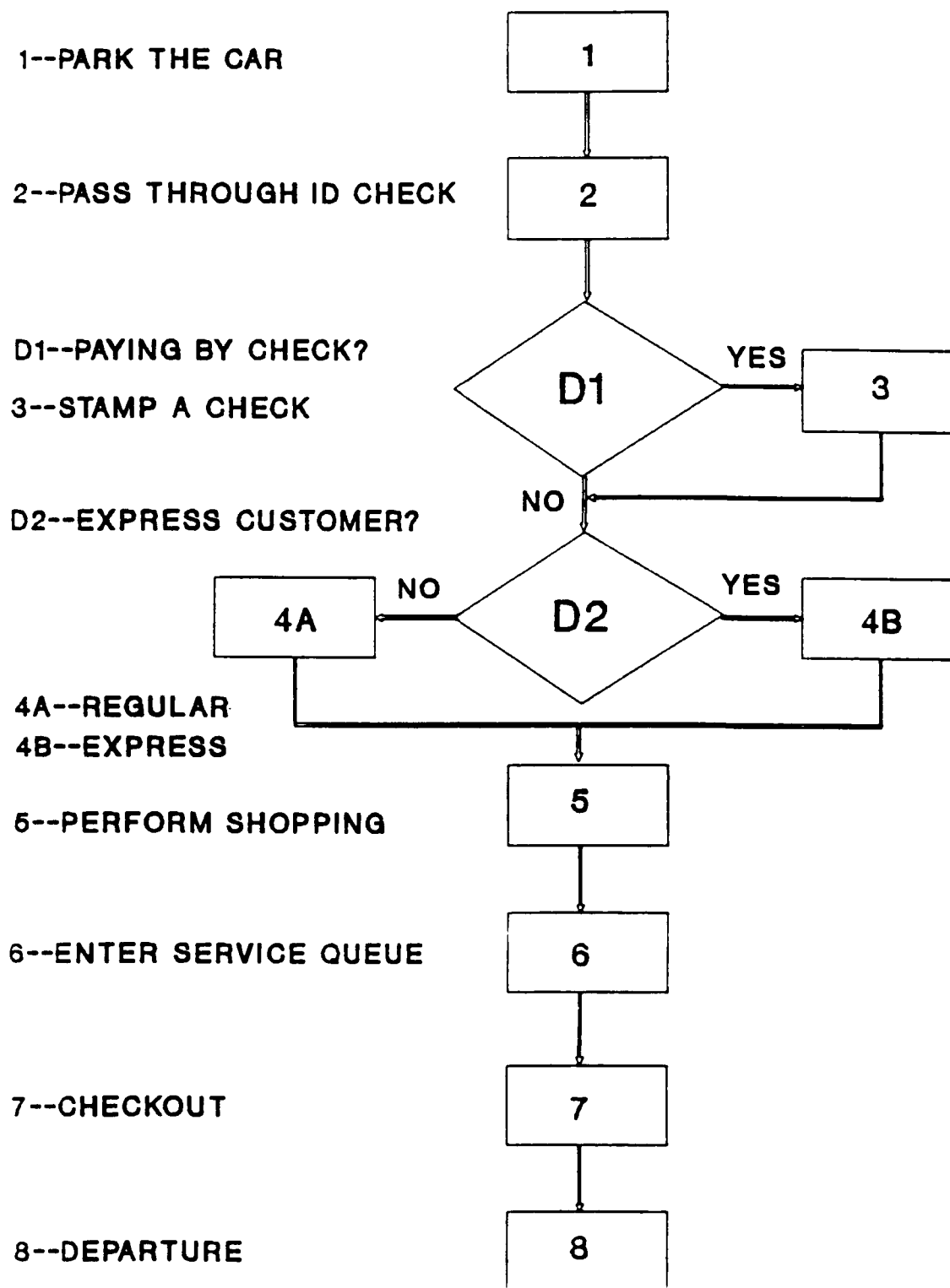


Figure 1. General Purpose Commissary Store Simulation Flow Diagram

number of available baggers, the number of people waiting outside the door at opening, store hours, and the number of service queues in the store together with the number of checkstands serviced by each queue. In addition, data must be input which details the customer arrival pattern by hour for a given store-day. When the necessary information has been entered into the model database, the simulation begins execution and instantly provides feedback regarding the current time (by hour), total customers for the day, number of customers currently in the store, number of available servers, and the expected waiting time of the most recent arrival in the service queue. It continues execution until reaching the end of a store-day, the basic unit of time for each run. It then "closes the door" but continues to process those patrons inside the store until all have been serviced. In this manner, GPCSS provides the capability for interested users to observe the dynamics of the service environment in real-time.

Changes can be made quickly to the basic set of input data and the model rerun to determine exactly what impact the changes made had upon the system. Herein lies the real strength of the model: its ability to provide quick turnaround with regard to any deviation from the normal operating parameters within the store environment.

This model is used as the primary analysis instrument for conducting this research effort. Chapter IV contains a detailed summary of all changes made to the original GPCSS.

This concludes the summary of previous commissary operations analysis research. The next section discusses the use of simulation modeling as an analysis technique and the issues that should be addressed when using a technique of this type.

Simulation Modeling Issues

The final portion of this literature review is concerned with the use of simulation as a statistical evaluation and analysis technique. Queueing problems present the analyst with a special challenge since the nature of each of the process mechanisms is often difficult to represent. When the interaction of these mechanisms is also examined, an analytical model is often unsuitable for investigation of the system. Simulation modeling has generally been regarded as an acceptable technique when analytical approaches are inappropriate. It has, however, also been generally regarded as a "higher risk" approach to statistical evaluation. This is due to the often complex nature of the systems which it is tasked to represent. As Gross describes:

While simulation may offer a "way out" for many analytically intractable models, it is not in itself a panacea. There are a considerable number of pitfalls one may encounter in using simulation. Since simulation is comparable to analysis by experimentation, one has all the usual problems associated with running experiments in order to make inferences concerning the real world, and must be concerned with such things as run length, number of replications, and statistical significance. (14:381)

In addition, the use of simulation models necessitates some recognition of the two-phase process of model verification and

validation. Verification is the process of checking the basic model logic for correctness. That is, the model is "doing what the programmer thinks it is doing." Validation is the process of deciding whether or not the model is a good representation of the real-world process. This is a much more difficult concept to resolve because it often requires judgement regarding the suitability of the model. Models constructed at the most elementary level in which the relationships between each of the relevant factors are clearly defined may successfully reproduce "reality" or "truth." But more often than not, large-scale system modeling becomes a series of compromises and estimations. Process assumptions are a recognized necessity when using simulation. And when the limitations of these assumptions are properly understood, "perfect" simulation gives way to "good" simulation. When highly complex, integrated systems are the objects of simulation, many simplifying assumptions are made for reasons of simplicity and practicality. When this happens, the utility and accuracy of the simulation will erode to some degree. It is determining this degree of erosion and its accompanying impact where judgement (with some assistance from statistical testing, perhaps) genuinely comes into play.

However, the advantages which are offered by accurate simulations make this analysis technique indispensable. A simulation model can be used to generate observations for a given system with a level of control and efficiency not possible during the collection of data within a real system. For this analysis,

the queueing configuration, arrival rates, service times, and number of cashiers can be pre-set and the system performance recorded for each variation of the system configuration. The analyst can decide how many observations are necessary for each configuration in order to reach a desired confidence level. Even though simulation is often time-consuming and computer-intensive compared to other analytical techniques, it is more efficient and flexible than real-system data collection. This is not to imply that simulation is a suitable replacement for the collection of real data - it is not. But capabilities of this nature create opportunities to extend limited real data to system configurations which are not possible or cost-effective to observe or simply do not exist. An example of this type of situation might be testing a communications system under nuclear-disturbed environmental conditions. For this effort, the Lackland AFB commissary operates using a separate service-queue for each checkstand. As a result, data cannot be collected on a single service-queue system. These "observations" must be simulated.

In addition, simulation modeling can fill-in "gaps" in data collection. The data used in this analysis was collected during the Functional Review. But the Functional Review was not concerned with and did not collect data on customer wait times. Wait time data, an important factor in the measurement of customer service, can be collected on the simulated system.

Furthermore, a simulation analysis of sufficient fidelity can often provide insight into systematic flaws which an analytical

model could not account for. Some examples for this environment are listed below:

- 1) A customer may leave the commissary without shopping because the lines are too long or there is a shortage of shopping carts or parking spots. This is called balking and is an important issue when considering customer service. Balking was not considered in the development of the Manpower Standard. Balking can be simulated and statistics collected.
- 2) Simulation models permit multiple output parameters which are often needed to provide a complete picture of a system. During periods with long checkout lines, there may be a wait for a shopping cart. In this case, the total waiting time would be an important measure of customer satisfaction.
- 3) Simulation is suitable for analyzing systems which contain stochastic variables. In this case, the arrival rate, the checkout time, and the number of items purchased are all stochastic variables.

Simulation modeling is a rapidly developing analysis technique. The growth of this type of analysis tool will largely be dictated by tighter fiscal policies throughout our society. When "live" testing becomes more difficult to justify in terms of cost-effectiveness, simulation will no doubt be relied upon at a much greater level than it is today. The assurance that accurate, representative simulation models are constructed for analysis will become more important than ever.

Summary

In summary, the literature which has proven most useful for this analysis effort has been concentrated in four main areas. Basic queueing concepts, selected queueing system applications,

historical research involving commissary operations, and the concerns associated with using simulation modeling as an analysis technique. The next chapter will address the methodology used in this research effort.

III. Analysis Methodology

This chapter will briefly describe the analysis research methodology employed in this effort in terms of the primary parts of the study. As a starting point, the general approach of the analysis is described to include the dual objectives of the effort. The Manpower Standard model and the simulation model are briefly discussed in terms of the roles that each play in the research. The organization of the effort is detailed within the research process. And finally, a short description of the data collection effort for the analysis is included which details data concerns for the research.

General Approach

The research methodology for this effort was broken into two segments to correspond with its dual goals. The initial portion of the design was intended to address the question of the suitability of the proposed AFCOMS Manpower Standard for Customer Service. The second portion of the study intended to determine the parametric sensitivity of the customer service environment. In addition, this research effort has evolved to include the development of a standardized process for performing future store analyses of this nature. That process is outlined in the following paragraphs.

Manpower Standard Model

The starting point for the research was the examination of the proposed Manpower Standard. This is an essential part of the

initial analysis phase, but only necessary prior to a revision of the Manpower Standard. The examination outlines an independent procedure for investigation of the HQ AFCOMS model development. It is **not** intended to faithfully reproduce the model developed during the AFCOMS Functional Review of Customer Service (Functional Review). It is, however, intended to satisfy the goal of accurately forecasting personnel requirements for the customer service system using a slightly different approach.

The primary goal of the Functional Review was to measure the manpower required to perform the intended mission of the AFCOMS customer service system: To assist and process customers through the customer service environment within Air Force commissaries. However, the Manpower Standard was based upon a data collection effort which was limited in scope and did not evaluate system performance in terms of a "Level-of-service" (LOS) measure. LOS represents the resource commitment of a given store to perform its mission and is measured by the customer service system performance. For a given arrival pattern, a store having an average customer waiting time of five minutes has a higher LOS than a store (with the same arrival pattern) having an average customer waiting time of ten minutes.

This research takes a more sophisticated view of forecasting manpower requirements. It incorporates additional measures of system performance directly related to LOS into the process of forecasting manpower requirements. This should provide a more realistic assessment of the customer service system needs by

recognizing that the process is not as rudimentary as simply calculating the manning requirements for a given store-month based upon the number of customers, number of days of operation, and number of coupons processed.

Simulation modeling will provide the underlying framework for conducting the Manpower Standard examination. The next section will describe the role of the simulation model in the research.

Simulation Model

The selected simulation model, GPCSS, required modification to create a parallel relationship between itself and the Manpower Standard model. Despite the intent for the evaluation of the Manpower Standard to use a more comprehensive approach than the development of the standard itself, it remained essential to create as close a relationship between the Manpower Standard and the simulation environment as possible. If the simulation model was to have credibility as a tool to reproduce those conditions which led to the development of the Manpower Standard, then GPCSS would have to undergo substantive modification. A detailed discussion of all model changes is found in Chapter IV. Another issue which would then have to be faced was the verification and validation (V&V) of the modified simulation model. This is addressed at the end of Chapter IV.

Research Process

The simulation model was intended to be used in each of the

two phases of the research. During the first part, it would be employed using store conditions documented during the Functional Review for both Lackland AFB and Rhein Main AB. These results would then be compared with the manpower requirements determined by the Functional Review. An assessment of this comparison would address the accuracy of the Manpower Standard and the usefulness of the simulation model as a future analysis tool. The second part of the research entailed a sensitivity analysis of the commissary customer service environment. The experimental design for this phase attempted to discover the identities of the most important factors in the system. With this information, a regression model could be developed to help predict (using historical input) the personnel workload required to support the customer service system for a given LOS. An effective tool of this type could prove to be extremely valuable to the management running the stores.

Data Collection

This research effort intended to use the same data as that collected during the Functional Review in support of the Manpower Standard revision. Most of this data was available from the Functional Review Division within the Directorate of Strategic Plans and Analysis (AFCOMS/XOF). As a result, extensive data collection was not required. However, limited data collection was necessary to obtain appropriate inputs for the simulation model to support congestion assessment and checkout processing time. In addition, inputs were collected which documented coupon-related

transactions, an item of considerable interest in this research.

This concludes the outline of the research methodology for this analysis effort. The next chapter will describe the development of the Manpower Standard and the simulation model used in the analysis, the Modified General Purpose Commissary Store Simulation.

IV. Description of Models

The models which will be described in this chapter include the AFCOMS Manpower Standard for Customer Service and the Modified General Purpose Commissary Store Simulation (MGPCSS), the model used in conducting the analysis. In addition, a discussion of the verification and validation of MGPCSS will conclude the chapter.

Manpower Standard

The underlying motivation behind this entire effort to better understand the dynamics of the customer service environment of USAF commissaries was an AFCOMS management interest in the revision of the Manpower Standard for Customer Service (Manpower Standard). As stated in Chapter I, the Manpower Standard provides the fundamental authority for the personnel authorizations in the customer service departments of AFCOMS stores. The revised Manpower Standard was the result of a two-year study to properly document the manpower levels required to perform the mission of operating the customer service system for each store. This study, the AFCOMS Functional Review of Customer Service (Functional Review), documented the manpower requirements of the customer service departments to include the functions of entry-control, cash-control, and grocery checkout. However, as the Introduction stated, all non-checkout function (e.g. entry-control, cash-control, etc.) manpower requirements were excluded from this analysis. Cashier-function labor requirements have a far greater impact upon level-of-service

(LOS) measurements than the other functions performed by customer service personnel.

The Functional Review study "... involved a complete measurement of the customer service departments utilizing work sampling as the primary work measurement method. Two operational audit measurement techniques, technical estimate and historical records, were used to supplement work sampling data." (3:1-1) The observational period began in April of 1987 and concluded in March of 1988. A total of 16 commissary locations were involved in the effort. Each of the sixteen commissaries selected for the data collection was observed for a three-week period. Those stores operating on a 5-days-per-week schedule were observed for fifteen (15) consecutive business days; those on a 6-days-per-week schedule were observed for eighteen (18) days; and those open every day were observed for 21 consecutive days. The Lackland AFB commissary was monitored from 27 May to 16 June in 1987. The Rhein Main AB commissary was monitored from 28 October to 18 November in 1987. Store size was disregarded for analysis purposes. The collected data was organized according to the three functions of the customer service departments. Adjustments were made to standardize the data according to a standard one-month operations period. Historical data was collected from AFCOMS accounting and operations functions (AFCOMS/AC and /DO) and prepared for regression analysis in the Manpower Standards Development System (MSDS), the statistical analysis package of the Air Force Management Engineering Agency (AFMEA) located at Randolph AFB in Texas. (AFMEA is a technical

evaluation center which supports the Air Staff in matters concerning manpower-sizing evaluation issues. They provide computational software support to Air Force agencies reviewing and updating their manpower strength authorizations.) The work-sampled manpower data was input as the dependent variable and each of the historical data categories was input as an independent variable for the regression analysis. Historical data considered as factors included 1) average dollar sales per month; 2) average number of customers served per month; 3) average number of items sold per month; 4) number of operating hours per month; 5) number of operating days per month; and 6) the average number of coupons processed per month. MSDS was run using the above factors and the resultant "best fit" model (the **Manpower Standard**) is as follows:

$$Y = -2485.8422 + 0.0568 (X_1) + 118.3235 (X_2) + 0.0110 (X_3)$$

where: Y is the man-hours required to operate the customer service department for one month

X_1 is average number of customers served per month

X_2 is the number of operating days per month

X_3 is the average number of coupons processed per month

The MSDS evaluation indicated that this model was the best predictor of customer service manpower requirements for each store for a given one-month period. The R^2 for the equation was .905 which indicates that the fit of the model is quite reasonable. Appendix F contains a summary of the data analysis which produced the Manpower Standard. Further detail regarding the study may be

found in the Air Force Commissary Service Functional Review Study Final Report. (3)

MGPCSS

While GPCSS was intended to be an analytical tool for the AFCOMS analysis staff, it was found to contain assumptions which were deemed unsuitable for this effort as well as some minor structural flaws. As a result, many changes were implemented which significantly changed the operation of the original model. Sarah J. Fritz, a recognized authority in the use of the SLAM programming language (used in GPCSS and MGPCSS) while stationed at the Air Force Operational Test & Evaluation Center (AFOTEC) from 1984-1988, was instrumental in making the necessary changes to GPCSS.

SIMULATION MODEL LANGUAGE

GPCSS and MGPCSS are both written in SLAM, a high-level simulation language. The following is a brief description of SLAM. Further detail concerning SLAM can be found in Pritsker (29) or Banks and Carson. (6) SLAM (Simulation Language for Alternative Modeling) is a FORTRAN-based simulation programming language which allows an event-scheduling and/or a process-interaction orientation toward modeling. (6:99) The event-scheduling orientation focuses upon events and their effect on the state of the system. This approach uses FORTRAN-coded "subprograms" to perform event scheduling, file manipulations, statistics collection, and random sample generation. (29:73) This structure is referred to as

"discrete-event modeling" because changes in the model occur at discrete points in time. Examples of this approach in MGPCSS include customer arrival, completion of checkout service, etc.

The process-interaction orientation focuses on systematic elements called "entities." They might represent things such as customers or transactions. Using this approach, the system traces the sequence of events and activities which confront an entity as it flows through the system. (6:99) Processes are represented by the nodes and branches of a network. Nodes generally represent events while branches normally indicate activities. Examples of this approach in MGPCSS would include shopping, checkout, waiting for service, etc.

The ability of SLAM to combine the FORTRAN and network-based structures "with interactions between each orientation greatly enhances the modeling power of the systems analyst." (29:74) This interaction of the parallel model structures allows events to alter the flow of entities in the network model and permits entities in the network to initiate events in the FORTRAN model. Both GPCSS and MGPCSS use this hybrid-modeling approach to simulation.

MODEL MODIFICATIONS

The most significant changes added to MGPCSS concern the operational policies for customer movement in a multiple service-line system (jockeying), customer departure prior to transaction (balking), cashier allocation and de-allocation, the frequency of simulation status updates, and the statistical distributions used

in the model. These changes will be discussed under subheading Structural Assumptions. In addition, the user-friendly interface which dominated much of the original simulation model (GPCSS) was removed. This results in the model being more dependent upon the user to understand both the necessary preparations for model input and proper output interpretation. But the modifications reduce overhead in the model operation, make it easier for the staff analyst to use, and make the model simpler to maintain & update when appropriate.

Program Events

FORTTRAN subprograms are used for event functions. Table 2 lists the events and their functions. Modifications to these events are described following Table 2. Those events which have not been changed or are not used in MGPCSS will not be listed in the event-change narratives.

Table 2. List of Events

Event	Description
1	Finds the shortest queue for customer.
2	Opens and closes checkstands/queues as needed.
3	Ends simulation at time xx(1).
4	Status check - # in store, # of cashiers.
5	Opens or closes an express line.
6	Allows customer to move to shorter queue.
7	Hourly changes - maximum cashiers, arrival rate.
8	Used to make sure closed queue is empty.
9	not used
10	not used
11	Assigns # of items and carts for each customer.
12	not used
13	Calculates waiting time, checkout time.

EVENT 1 - Event 1 now checks for the shortest queue rather than the previous method which checked for the longest queue.

EVENT 2 - Slight modifications to opening/closing process. One significant change made to the cashier deallocation scheme is the restriction previously imposed which limited cashier removal to one per hour. This was changed to a maximum of one every six minutes. This reflects greater flexibility for responding to changes in demand. It can create greater fluctuations in the cashier staffing levels but offers much higher utilization rates and can provide more assistance in determining real requirements when "smoothing out" the genuine cashier schedule.

EVENT 3 - Slight changes were made to end-of-day processing.

EVENT 4 - Changes to status update check. The congestion factor update was changed slightly to a more efficient structure. A calculation was added to the status update to check for a customer/cashier ratio value. This ratio is related to the "balking" capability added to the model.

EVENT 6 - Jockeying. This event is completely new. More details are found in the section called Jockeying.

EVENT 7 - This event controls the updates to the changes in customer arrival rates and, when in use, the maximum number of cashiers for each half-hour. Most of this code is new.

EVENT 8 - This action is a check to ensure no one is in a service-queue which is about to close. Problems had been encountered with this occurrence, so this event was created to correct the problem.

EVENT 13 - Changes were made to the algorithm which calculates waiting time, assigns time attributes to customers, and calculates average checkout time for store day.

Model Assumptions

There are two types of modeling assumptions used in MGPCSS: data assumptions and structural assumptions.

Data assumptions normally address the scenario being evaluated. These are quantitative assumptions and can easily be changed. A list of the data assumptions used in MGPCSS can be found in Table 3.

Structural assumptions concern basic system operation and involve simplifications of reality. These assumptions are an integral part of the model logic, and are not easily changed. Examples of these assumptions include operational concepts such as jockeying, allocation and deallocation of cashiers, statistical measure calculation, and balking.

Table 3. Data Assumptions

Data Element	Source
customer arrival data	AFCOMS Forms 28
cust interarrival times	Exponential; actual hourly arrival values
average checkout time	calculated from AFCOMS Form 10 data
dist of chkout time	composite general (below)
balking	estimate
bagger transit time	direct observation
% express customers	GPCSS
customer shopping time	GPCSS
# of shopping carts	store manager
# of queues	store manager
% customers using coupons	AFCOMS PTD dept report
average coupons/customer	calculated from AFRCs data

Model Structure

The structural foundation of MGPCSS is that of a M/G/s model. This means the customer arrivals are specified at a given rate per hour and are assumed to have exponential interarrival times (M). The service rate is defined to be a general distribution (G) which is more precisely described in the next section. The number of service channels is input according to user specifications and is denoted by "s".

Checkout Time

With respect to the distribution used for the checkout time for each customer, questions arose regarding the basic assumption of how to best simulate a single checkout event. Moulder, in GPCSS, used a data sample he had obtained from the commissary at Wright-Patterson AFB. With this collection of data points, he was able to derive a distribution to represent service time. However, Moulder uses a single probability draw to determine the customer service time and does not account for any factor variance within the service process. For this effort, the structure of the Manpower Standard model indicated that coupon redemption is a major factor in setting manpower requirements for customer service. As such, it was considered essential to explicitly account for this impact in the simulation.

For MGPCSS, a composite variable was created to account for the apparent impact of coupons redeemed by commissary patrons on customer service manpower requirements. However, this composite variable would have to be designed so that the resulting average checkout time derived from the simulated data corresponded with that which was measured during the Functional Review (for each base). With the data available for this effort, an average checkout time for each base was computed based upon the total cashier labor hours recorded during the observation period divided by the number of customers during the same period. This average time was used as a baseline for comparison with the data produced by the simulation.

The composite variable was composed of two basic parts: An initial random draw which would reflect the service time attributed to a customer who did not present coupons for redemption at the time of transaction; and a second step which would reflect the impact of a customer using coupons during his purchase. The second part of the composite was also broken into two parts: An initial random draw to determine if this customer did or did not use coupons; and a draw to determine how many coupons were used if the first draw determined they were to be used. If the previous draw determined coupons were not to be used, no second draw is performed. If coupons were used, the second draw value is converted to additional service time for the transaction. With this value, a total service time for the transaction is computed. One important data limitation noted in Chapter I: The percentage of people using coupons and the average number of coupons used during a transaction were not available for the observation period for either store. Lackland AFB commissary data from June 1989 was used as a fundamental assumption for determining the likelihood of a person using coupons in the store simulation. The model assumes that this probability of using coupons is not affected by seasonal influence. Data was not available for Rhein Main AB as a second check for this probability. This would certainly be a factor which could be re-examined at a very simple level to verify its accuracy and determine what factors (if any) cause it to fluctuate. Lackland AFB commissary data from May-June 1989 (same seasonal period as the Functional Review but two years later) was analyzed

to determine how many coupons would normally be used during a transaction which included coupons. No data was available for Rhein Main which would correspond with the season during which the Functional Review was conducted at that location, but discussion with AFCOMS staff indicated that overseas commissaries will often be quite different from CONUS stores with respect to coupon usage. This should also be re-examined to verify what the parametric boundaries are for this variable and what factors cause it to fluctuate. Coupons obviously have a tremendous effect on the manpower requirements for the customer service system, and AFCOMS would be very prudent to explore more precisely the extent of that effect. For the purposes of this effort, these limitations on coupon transaction data have not proven detrimental to the overall analysis.

Queueing Configuration

The queueing configuration for the simulated commissary is chosen during the store initialization phase of MGPCSS. The configuration may be specified in any fashion in which a given service-line will "feed" into at least one checkstand. The most common queueing configurations found in USAF commissaries include a single service-queue (sometimes called a "snake" because of its winding shape), dual service-queues where each line serves half of the available checkstands, and the one-to-one service-queue system where each line serves a single checkstand. Figures 2 & 3 graphically illustrate examples of each configuration.

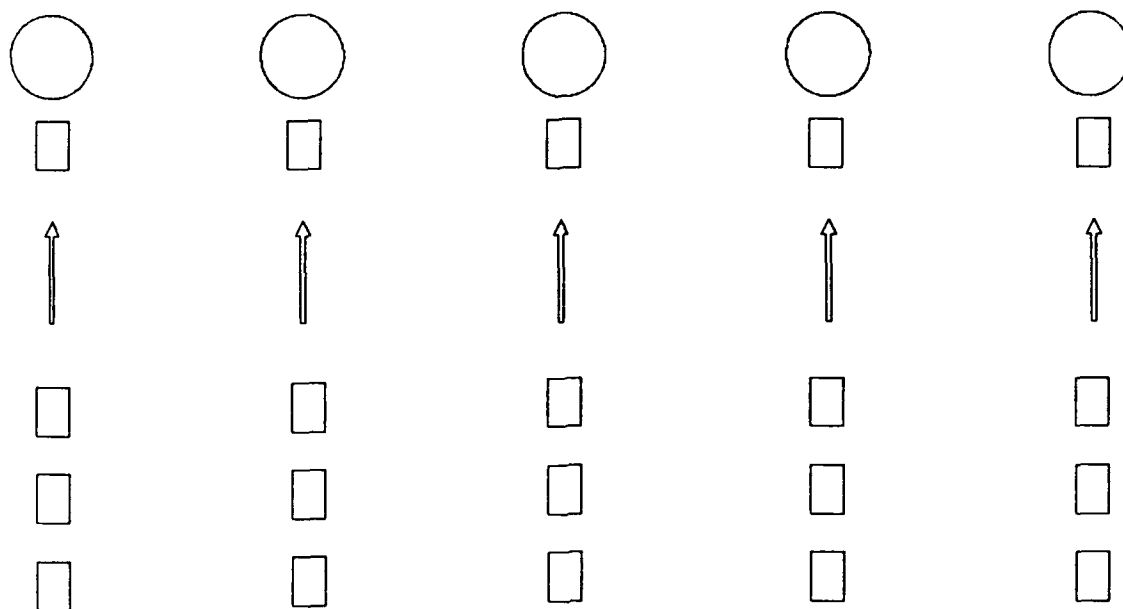


Figure 2. One-To-One Service-Channel System

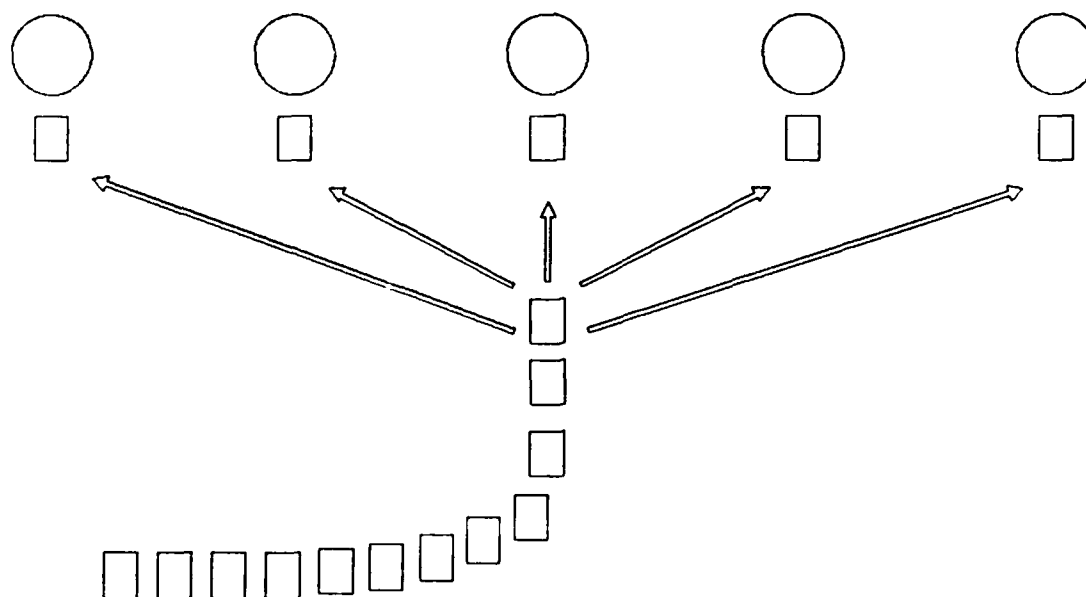


Figure 3 Single Service-Channel, Multiple-Server System

Many studies (including Dorrough and Holliway (10)) have clearly demonstrated that the single-queue service system is the fairest, most efficient method of processing customers, but it is still not widely used because of physical constraints in stores as well as customer resistance to these systems. As mentioned earlier in Chapter II, Jones (18) found that many customers find this system uncomfortable even though they may actually spend less time waiting in line. It remains quite uncommon in commercial stores.

At the time of the Functional Review, the Lackland AFB commissary was configured as a one-queue/one-checkstand queueing system. Rhein Main was setup as a single service-queue system which serviced all ten checkstands in the store. However, both stores can be configured for either of the two basic queueing systems within the simulation.

Jockeying

As was introduced in the queueing theory review in Chapter II, customers will often move from one service-line to another to shorten their wait for service when in a multiple-queue service environment - a situation commonly called "jockeying." The ability to jockey or not jockey will significantly impact maximum waiting time. In either instance, a customer must choose a given service-queue after shopping has been completed as normal. But without jockeying, the customer is unable to change service-queues even if new, shorter queues are opened. This results in the customer enduring an uncharacteristically long wait. GPCSS does not allow

jockeying. But clearly, in multiple service-line configured stores (such as Lackland), jockeying is quite common. MGPCSS does allow jockeying when a new service-queue opens by moving the second person in a given service-queue to the new service-queue. In reality, jockeying is an extremely complex event due to a variety of different elements. The customer arriving first at the new queue is not necessarily the one who has been waiting the longest, and may not have waited at all. Intuitively, the first-in-line customer would remain in the original service-line since basket-unloading may already have begun. The second-in-line customer would probably only move if the new service-line was very close and they felt confident of being serviced first. Furthermore, this observation of jockeying is strictly analytical. Basic human nature also plays a large role in how jockeying is performed in any location due to the individual standards which dictate jockeying for each person.

For this research, a series of three sets of model runs was executed during the model development phase to explore the impact of jockeying on the service environment. The first set of runs used the original model (GPCSS) structure which did not allow jockeying. An intermediate set of runs used a model structure which allowed jockeying only when an additional service-queue was opened. The final structure, which was incorporated in the final form of MGPCSS, provides for a jockeying "check" during each system update. That is, when a multiple service-queue configuration is in use, the simulation checks to see if jockeying would be useful each

time it updates the store status. The data from these runs indicates that the provision of jockeying in MGPCSS has little effect on the average waiting time for patrons. But it will have a substantive effect on those forced to wait the longest. Table 4 shows the results of allowing jockeying.

Table 4. Effects of Jockeying

Description	Customers	Maximum Wait(m)	Average Wait(m)
No jockeying	3052	19.38	8.61
Jockeying once after opening queue	3052	15.48	8.78
Jockeying periodically after opening queue	3052	14.79	8.78

The data listed in Table 4 was based upon a basic scenario typical day at the Lackland AFB commissary with respect to the customer arrival profile and the expected service time per customer.

Cashier Allocation/Deallocation

The allocation/deallocation scheme in MGPCSS has two different options for controlling cashier resources. The number of available cashiers may be determined either by the internal MGPCSS allocation/deallocation algorithm or through user input in half-hour increments. When the model is allowed to control cashiers, it does so based upon a scheme in which a cashier is added when needed and removed when not. Customer waiting time is controlled according to the AFCOMS policy of 15-minutes maximum wait and cashier idle time is minimized as much as possible.

The determination of when cashiers are needed or not needed is set by a parameter in MGPCSS. This parameter reflects the degree of managerial control with respect to the checkout environment. It will be referred to as the "add checker" policy. It may be set to 15 minutes (low managerial control) to reflect a lower LOS standard to conserve cashier hours, or it may be set to 5 minutes (high managerial control) when a higher LOS is desired. Each time MGPCSS does a system update (set by input parameter), the waiting time for the most recent queue arrival is calculated. If this number exceeds the parameter value set for the add checker policy, and there is at least one closed checkstand, another cashier is added to the system.

For the removal of a cashier, the process differs with respect to queueing configuration. When a single-line queueing system is in use, a cashier will be removed if the customer waiting time falls to three minutes or less. When a multiple-line queueing system is in place, a cashier will be removed when the most-recently added cashier is idle during a system update. The design of the model dictates that the most-recently-added cashier will nearly always be the most likely cashier to be idle for more than a few moments. Service-queues are checked in the same order each time a customer is being assigned to a checkout line, and the most-recently-added cashier is always checked last.

Customer service managers would not likely have as much flexibility as this model allows. However, the service manager should have more flexibility in assigning cashiers than the policy

within the model of assigning them only at half-hour intervals. What the model provides in this case is a choice of managing the cashier staff in an unconstrained environment with respect to personnel limitations (breaks, lunches, other duties) and managing the staff with increased restrictions regarding their duty schedules.

MGPCSS gives the analyst the capability to run a given set of input conditions to determine the number of cashier hours necessary to achieve a given LOS. However, the cashier schedule created by the automated system will often fluctuate more than would likely be the case. Given this, the analyst can use the initial schedule created during the first run and manually adjust it so as to "smooth out the bumps" in the allocation levels while maintaining an equivalent number of cashier hours. The analyst then inputs the cashier levels directly using the alternative MGPCSS cashier allocation option and re-runs the simulation. The output will indicate if a similar LOS is achieved using the modified manning schedule. If not, further adjustments can be made and the simulation again re-run. Since the model has a fairly short run time, several iterations can be made within an hour. This option of controlling the cashier allocation was not essential for conducting the Manpower Standard analysis, but it provides great flexibility when addressing the question of total cashier hours.

Balking

Also introduced in Chapter II, balking is a queueing event in which a customer refuses to enter the service-queue after arrival. In reality, this may be caused by many different factors: Long service lines, desired products which are unavailable, no shopping carts, change of shopping plans, etc. At the same time, while balking is not usually a common event, it is a very real occurrence for almost any type of activity. For AFCOMS, its impact is virtually unknown and consequently, unrecognized.

For MGPCSS, balking is linked to two sets of conditions. It will occur when limited resources such as parking places or shopping carts are completely unavailable due to their use; it will also occur at a rate of 20% when the customer/cashier ratio is 8:1 or greater for the current service conditions. This is not based upon quantitative justification, but this is a very real phenomenon and should be accounted for to some degree. This means that a customer would have a 1 in 5 chance of not proceeding to the shopping phase when a service condition exists which roughly corresponds to a 25-minute average wait for checkout service. This rate is probably higher than reality, but it is assumed at this given rate for the analysis. Frey contends that "At the commissary, long lines do **not** usually cause customers to leave the store. However, they can result in loss of future commissary sales by causing customers to do future grocery shopping at off-base establishments." (12:1) But there exists no substantial data to either support or refute the frequency of this phenomenon one way

or another. However, while people may often wait for parking places, carts, or other constrained resources, there are limits. Defining those limits is where the difficulty lies. Yet another variation of this situation concerns customer shopping habits. GPCSS contains no provision for a customer who changes shopping plans but does not balk after observing long waiting lines for checkout service. Common sense dictates that this occurs at some small rate. These customers may instead choose to use the express line to purchase a few items only, or even choose to expand their purchase list in order to lengthen the time between shopping trips.

These events are very difficult to account for quantitatively, but should receive some recognition of their impact. Further investigation of these conditions would make the revised model more useful.

Simulation Output

Several output reports were specifically designed for this analysis. For the principal summary, each simulation run is identified through a set of six parameters: Day number, maximum number of checkstands, number of service-queues, number of arrivals versus expected number of customers, average checkout time, and the add cashier policy value. The primary response variables defined for this phase are cashier hours, cashier utilization rate, maximum wait time and average wait time. Additional output statistics collected include the number of customers generated by the model, the standard deviation of the average wait time, the percentage of

customers balking, and the percentage of customers waiting more than 15 minutes. These statistics were collected to clarify the state of the system and assist in determining the reasonableness of the simulation. Other output files were used primarily during error debugging and model verification and validation.

MODEL VERIFICATION AND VALIDATION

As was briefly described in the Chapter II, an important part of the model development process is the model verification and validation (V&V). V&V is a two-part procedure intended to establish scientific credibility for the model. The objective of the verification phase is to ensure that the computer code is performing as intended. The objective of the validation phase is to demonstrate that the simulation output adequately represents true system behavior. Numerous methods have been developed to aid in the V&V of computer simulation models ranging from informal, subjective comparisons to formal, statistically-intensive procedures. (6:376-377) Formal statistical tests are usually not worthwhile unless the existing system being modeled is nearly identical to the simulated system, and the response variables can be measured and collected for the existing system. For this research, the existing system (the commissary customer service environment) was observed and its operating conditions recorded (the Functional Review), but insufficient data was collected regarding customer queueing conditions. Only those factors

directly related to the customer service workload determination were thoroughly documented. LOS measures were not collected. While this does not present any problem for the verification phase, it does pose limitations for the validation process.

Verification

The following steps were taken to substantiate verification of the computer code:

(1) MGPCSS uses SLAM-generated statistics whenever possible to ensure system reporting accuracy.

(2) Statistical calculations were performed to check the basic functions of the model. Those calculations of highest interest are written to the summary output file. They include the following:

a. The expected number of customers (based on the hourly arrival rates) and the actual number of customers generated during the simulation (based on the number of entities counted passing through the first activity)

b. Average service time (compared with input value)

c. Maximum cashiers used (compared with input value)

(3) Some statistics necessitated multiple calculations to verify model accuracy. An example of this is the cashier utilization rate. It is first determined by using the resource utilization function in SLAM (RRAVG) and then again by an internal model algorithm during the status update process. (However, the SLAM function is not a meaningful statistical measure when multiple

service-queues are in use because a separate calculation is made for each cashier and necessitates aggregation).

(4) All customer wait times are preserved and later processed to calculate the average wait time at the conclusion of each run. This value is then compared to the average wait calculated in SLAM (FFAVG). Furthermore, the ten (10) highest individual wait time values are checked for outliers. (It was this procedure which was primarily responsible for identifying the need to add jockeying to the model). Finally, the Maximum wait time is calculated as both the wait time of the 99th percentile customer and the mean of the highest 1% of recorded wait times for comparison. All calculations involving Maximum wait time data use the 99th% values.

(5) A status update of the system is performed every three minutes (user-controllable) of simulated store time. As noted earlier, this update displays the hour #, total customers served, current customers in the store, current cashiers on duty and expected wait time for the most recent arrival to the service-queue(s). This output report was part of the original GPCSS and was retained as an additional verification check.

Validation

Validation testing is normally one of two types: Subjective or objective. Subjective testing to support model validation requires the judgements of people familiar with the system being modeled. AFCOMS staff input indicated that process logic and operations assumptions were reasonable. In addition, the sensitivity of model

output to changes in model inputs was observed for many different input combinations and the resulting changes in the model output were reasonable. Objective tests are more substantive and are used to compare the system's actual performance with the performance of MGPCSS. Since data was not collected on customer wait time (an important parameter in the simulation) during the Functional Review, a **formal** statistical test comparing queueing system performance was not practical. However, cashier utilization data was recorded during the Functional Review. With this in mind, a validation methodology was created which provides a semi-independent assessment of the simulation model.

A linear model of the average customer waiting time was developed using cashier utilization and customer wait time data produced by the simulation. This presents an uncomfortable situation, since it involves the use of data from two parameters from within the simulation to "validate" the simulation. But an informal check, using estimated wait time, should still be considered a useful tool in this process.

The regression equation to estimate average wait time (WAIT), using cashier utilization (UTIL) as an independent variable, is as follows:

$$\begin{aligned} \text{WAIT} &= -60.45 + 76.18 (\text{UTIL}). & .7935 \leq \text{UTIL} \leq 1.0 & \quad \text{VAL1} \\ &= 0 \quad \text{where } \text{UTIL} < 0.7935 \end{aligned}$$

This model will be referred to as VALIDATE 1 (VAL1). It was found to have an $R^2 = .67$. While VAL1 accounts for only two-thirds of the variation in the data, it should be considered sufficient for this informal analysis. A quick test of VAL1 indicates that it

looks reasonable (using VAL1, wait times range from 0 to 15.7 minutes) and is as objective as possible.

The next step in this informal process is to step ahead in this research to Chapter VI. This, too, may be considered unorthodox with respect to conventional validation procedure, but it is necessary to "borrow" the linear model developed through the sensitivity analysis which explains the relationship between cashier hours and the set of independent variables. This model, labeled CHOURS, is described in detail in Chapter VI. The selection of this model for this process was not planned. But because the variables in this model are customers, checkout time, and customer wait time, it naturally provided a perfect vehicle for using the Functional Review data in a check of reasonableness for MGPCSS. VAL1 was used to determine an average customer waiting time for each day of the Functional Review data collection period, and these values, together with the documented figures from the Functional Review regarding customers served and calculated checkout times, were used as inputs to CHOURS. Table 5 summarizes the results.

Despite the differences between the two cashier hour totals, the agreement between the model calculations and the observed totals appears very consistent. There is obviously some factor which is unaccounted for in the model computations, but nonetheless the model appears to replicate observed conditions quite well. The predicted hours are consistently higher (about 4%) than the

documented hours recorded during the Functional Review. Three possible reasons for the difference in cashier hours are:

1) During the Functional Review, a checkstand was only considered open if a cashier was at the checkstand. If he/she was making a trip to make change or "unshopping" (returning items left at the checkstand to the shelves), the checkstand was considered closed. The Functional Review counted this time as cashier labor, but as a different category of labor than this study is measuring.

2) In general, managers are able to use cashiers in other store areas during slack periods (for tasks like unshopping), or move personnel into cashier duty from other store roles during peak periods. This managerial flexibility is not built into the model. As such, the cashier utilization rate observed during the Functional Review will invariably exceed the model prediction, and the resulting man-hours will be lower than predicted levels.

Table 5. Predicted Vs. Observed Man-Hours (Lackland AFB)

Day	Customers	Service Time	Estimated Wait	Cashier Hours MGPCSS	Hours Observed	Total Idle	Cash Util
1	3008	2.67	15.0	141.1	134.75	1.00	.99
2	3142	3.23	14.2	176.1	171.50	3.25	.98
3	2191	3.34	15.0	130.6	122.75	0.75	.99
4	2992	3.55	15.7	180.3	177.50	0.25	1.00
5	2044	3.12	15.7	115.7	106.50	0.25	1.00
6	3081	3.10	15.0	166.1	160.75	1.75	.99
7	2168	2.83	11.9	114.7	107.25	5.00	.95
8	3001	3.04	11.2	163.5	161.50	9.25	.94
9	2590	2.84	13.4	132.8	127.00	4.25	.97
10	2743	3.07	13.4	149.9	145.00	4.50	.97
11	1942	2.70	15.0	97.9	88.75	1.25	.99
12	2899	2.63	15.0	134.5	127.75	0.75	.99
13	2168	2.80	14.2	111.8	103.50	2.50	.98
14	2558	2.88	8.1	138.0	136.00	13.25	.90
15	2563	2.94	15.0	134.4	127.75	1.75	.99
16	2822	3.39	15.0	165.6	161.25	2.00	.99
17	2106	3.15	15.0	120.3	111.50	1.00	.99
18	2672	3.26	14.2	153.4	147.75	2.75	.98
Total		3.04		2526.8	2418.75		

3) The rules which the model uses to determine whether a cashier is busy or idle are no doubt more precise than those used by human observers during the Functional Review. One of the clear-cut advantages of a simulation over a real system is in the precision of the data collection. Since the entire system is created within the computer environment, anything which is of any interest to the system observer can be collected with perfect precision and absolute consistency, conditions which are still beyond human-involved task processing. Time recorded as idle in the simulation would very likely go unnoticed or simply ignored during an observational period recorded by people. But to expect such an observational process to become more precise for this type of effort is probably unrealistic. As a result, idle-time is more carefully recorded by the simulation and will result in the creation of more hours being necessary to perform the customer service mission.

A four percent difference between the simulation results and the Functional Review observations seems well within a natural "gap" created by the environmental differences and circumstances.

Based on the verification and validation effort, MGPCSS is considered a valid representation of a commissary operations environment.

Summary

This chapter has discussed each of the two analysis models central to the research objectives, the Manpower Standard and MGPCSS. The methodology of the Functional Review effort which led directly to the development of the AFCOMS Manpower Standard model was profiled, and the simulation model used for this effort, MGPCSS, was described in terms of the changes made to the original model (GPCSS) and the rationale for making the changes. Finally, a verification and validation process for MGPCSS provided the

justification for its use in this task. The next chapter will outline the analysis procedures and experimental design used in conducting the simulation analysis.

V. Analysis

This chapter will outline the blueprint of the data analysis methodology for this research. It addresses each of the systematic approaches used in the examination of the Manpower Standard and in the experimental design of the customer service system sensitivity analysis.

Manpower Standard

The organization of the AFCONS Manpower Standard investigation was broken into three separate statistical computations of cashier labor requirements for each of the two subject stores: (1) The number of cashier hours observed during the Functional Review data collection; (2) The cashier hour requirement predicted by the proposed Manpower Standard; and (3) The cashier hour total calculated from the linear regression model which was developed from the simulation analysis of the commissary environment using the Functional Review data base.

For the first of the three comparative measures, the hours were aggregated over the observation days during the Functional Review data collection to determine a grand total of cashier hours (for grocery checkout-related duties) observed during the process. This measure will be identified as OBHRS during the analysis.

For the second measure, the proposed Manpower Standard model was evaluated using an expected value (based upon commissary historical data) for each of the variables in the regression

equation. This measure will be identified as MSEXP. A second calculation using the same Manpower Standard model was performed which incorporated the customer levels and days of operation observed during the Functional Review. This will be called MSFR. For each computation, a percentage of the total hours is deducted from the grand total to account for the proportion of hours which are not being measured in this study.

The final measure was subject to some debate. On one hand, the MGPCSS could have simply been run and the results aggregated for a given store-month or the Functional Review observation period. But because of the stochastic nature of the model, value deviations for customers processed, checkout time, and coupons redeemed would bias the comparison somewhat. Furthermore, no simple standard for level-of-service (LOS) could be imposed. As a result, the linear model (CHOURS, p.77) developed during the sensitivity analysis portion of this study became the best evaluation tool candidate for the manpower standard comparison. CHOURS, as the following chapter substantiates, is an excellent predictor of cashier hours based upon customers, service time, and LOS. This model was then used to calculate two different parameters. LMEXP incorporated the same expected customer levels as were used by MSEXP. LMFR was computed using the same arrival rates as were used by MSFR. The details and results of this exercise are found in the next chapter.

Sensitivity Analysis

The five factors believed to influence manpower requirements and therefore evaluated in this analysis are:

- 1) queueing configuration: either a single service-queue or a service-queue for each checkstand;
- 2) customers: number of arrivals less number of balks;
- 3) checkout time: Data from the Functional Review indicates it varies from day to day, and from store to store, due to differences in order size, coupons, customer shopping habits, and mix of cashiers; It may seem unusual to include this as a factor in the experimental design, but preliminary investigation indicates checkout time may differ enough from one day to the next in the same location to suggest that the elements which influence it can differ quite substantially. However, there is not enough evidence available to indicate the exact relationship between checkout time and the secondary factors (coupons, order size, habits, cashier mix) to suggest that checkout time can be eliminated as a primary factor and one of the secondary factors substituted. More investigation into this situation is necessary.
- 4) average customer waiting time: as the number of cashier hours increase, waiting time usually decreases (during periods of long waits, a cashier is never idle; with no waiting, at least one cashier may be idle); and
- 5) store identity: (1 for Lackland, 2 for Rhein Mein): this was included to evaluate whether there is a difference among stores which cannot be explained by the previous four factors; interactions are not included between the store and other factors;

It is difficult to judge, without some preliminary analysis, which of the five primary factors and six interaction terms will significantly affect the cashier hours. A regression procedure ideally should include 20 times more observations than the number of independent variables. (34:91)

The necessary number of runs can often be reduced through a **preliminary** Analysis Of Variance (ANOVA), which will identify the

factors and interactions that significantly impact cashier hours. For this type of analysis, the total number of factors must be restricted to a limited number of levels. As such, the queueing configuration factor uses two levels (single service-queue and multiple service-queue). Customer arrivals and service times were each grouped into six (three for each base) input levels; However, because the number of arrivals and transaction service times are stochastic variables, these input values will rarely match exactly with the data generated during a simulation run. Tables 6 and 7 illustrate the extent of the variation involved. Moreover, wait time is a response variable and cannot be assigned for a given run. Following the preliminary runs, wait time was converted to three levels using the following criteria:

0-5 minutes	Level 1
5-15 minutes	Level 2
15+ minutes	Level 3

It is not necessary to include "store" as an indicator in this preliminary analysis. A glimpse of the data collected during the Functional Review reveals the hours for Rhein Mein vary from 50 to 90; Lackland, from 85 to 180. It does not require a statistical test to establish confidence that there is a significant difference due to the store, perhaps only because of economies of scale. Lackland has a total of 22 checkstands while Rhein Main has 10. "Store" will be included as a possible independent variable.

Factors and one-way interaction terms were fitted to a least squares, best fit regression, using the following steps:

- 1) Run the simulation model to generate observations, using a limited number of levels for each parameter, for the ANOVA.

- 2) Identify the significant factors and interaction terms; factors are considered significant if the probability that the variance is due to chance alone is greater than 25%; this criteria is based on the limited levels of the factors and because this is a preliminary analysis;
- 3) Determine the number of simulations desired (# possible independent variables x 20); run the simulation to generate additional observations with all desired combinations of factor levels;
- 4) Run regression using the significant factors, interaction terms, and store identifier as independent variables;
- 5) Delete factors and interaction terms which were not significant and rerun the regression;
- 6) Plot the residuals to determine if they are randomly scattered; and
- 7) If residuals are not random, try transformations (quadratic or logarithmic) and rerun the regression.

This procedure will be used to determine an estimation of cashier hours as a function of the primary and secondary terms. Likewise, valid regression models for both Average and Maximum waiting times (for the 99th percentile customer) are also of considerable interest.

Experimental Confidence

Cashier hours is the response variable we are most interested in when examining the Manpower Standard and customer service system sensitivities. But a single observation for each set of treatment levels may not provide the statistical assurances needed to sustain analytic credibility in the simulation model. To achieve a given threshold of statistical "confidence," certain factors must be considered. Cashier hours is sensitive to many stochastic

variables and can vary substantially from one day to the next for a given system configuration. To determine the number of simulation runs required to meet the selected confidence level, two sets of preliminary sample runs were made in order to learn more about the system response variables. The number of required model observations is largely determined by the variation found in the sample runs (assuming that the sample variance is a good estimate of the population variance). The other parameters used to determine the number of required runs are defined by the analyst. The formula for calculating the required number of simulation runs is as follows (29:55):

$$\text{Number of Observations: } N = (t_{a,n-1}s/g)^2$$

where: $t_{a,n-1}$ is the t-statistic value for confidence level α and $n-1$ degrees of freedom

s is the standard deviation of the sample

g is the half width of the confidence interval

Tables 6 and 7 list the output response variables of interest for the sample runs. The complete output file is listed in Appendix B. TWO sets of ten runs each were made due to the nature of the response variability in the model. True variance for Cashier hours, Maximum wait time, and Average wait time cannot be calculated in one set of runs. The simulation is designed to emphasize either a constant customer waiting time or a fixed cashier schedule which holds cashier hours constant. Two sets of runs (variation for both Average wait time and Maximum wait time

can be measured concurrently) allow the analyst to determine a truer measure of response variation for each of the selected variables.

Table 6. Preliminary Runs
Maintain Average Wait Time, Vary Cashiers

Customers	Service Time	Cashier Hours	Maximum Wait	Average Wait
2757	3.08	154.3	22.86	7.49
2764	3.14	155.1	22.81	7.92
2802	3.07	153.3	23.55	7.51
2795	2.97	149.1	21.38	7.08
2653	3.08	148.7	22.74	7.31
2775	2.94	147.4	22.52	7.17
2661	2.99	144.3	23.00	7.04
2785	2.97	149.3	22.59	7.05
2713	3.07	147.1	24.56	7.45
2753	3.06	149.7	23.61	7.87
$\bar{x} = 2746$	3.04	149.8	22.96	7.39
$s = 53$.065	3.43	0.83	0.32

Table 7. Preliminary Runs
Maintain Cashiers, Vary Average Wait Time

Customers	Service Time	Cashier Hours	Maximum Wait	Average Wait
2757	3.08	155.8	21.63	6.01
2764	3.14	155.9	25.57	9.02
2802	3.04	155.8	26.84	7.67
2795	2.95	156.3	25.12	8.21
2653	3.11	155.1	20.05	5.39
2775	3.01	156.0	23.37	6.48
2661	2.96	156.0	20.32	5.48
2785	3.02	156.9	21.08	6.37
2643	3.08	155.2	17.03	3.83
2716	3.02	156.1	21.68	5.85
$\bar{x} = 2735$	3.04	155.9	22.27	6.43
$s = 62$.062	0.51	2.97	1.51

The choice of a specific confidence interval depends upon the degree of accuracy desired for the analysis as well as an understanding of the computer time necessary to perform each run. A confidence interval of \pm four (4) hours was chosen for the Cashier hours measurement. Four hours is equivalent to one cashier for one half of one workday. As was mentioned in the explanation of model validation, store management has some flexibility to use cashier personnel in other capacities as well as employing other store workers as cashiers if the situation warrants it. Under these circumstances, four hours seems a reasonable standard of uncertainty. However, there exists wide variation in AFCOMS store sizes and future examinations of this type might look at making this parameter a function of the normal daily cashier requirement for each store rather than a preset value. A confidence interval of \pm two (2) minutes was used for the maximum and average wait time parameters. This selection of half-intervals is also subject to some debate. They were chosen as a result of looking at the test run outcomes and talking with store operations personnel. Future endeavors might study these variables more closely in an effort to more rigorously define any differences between the wait time variables. For now, the chosen half-intervals do seem reasonable for this effort.

A confidence level of $\alpha = .80$ was chosen as a result of personal experience while assigned to the Air Force Operational Test and Evaluation Center in New Mexico. An 80% level of confidence was quite common in operational test issues. However,

a higher level of confidence (perhaps 90%) may have been more appropriate for this analysis and should be incorporated into future research of this nature. Table 8 contains a summary of the parameters used in the calculation of required observation.

Table 8. Number of Observations

Cashier Hours	Maximum Wait	Average Wait
$t_{.80,9}=.883$	$t=.883$	$t=.883$
$s=3.43$	$s=2.97$	$s=1.51$
$g=\pm 4.0$	$g=\pm 2.0$	$g=\pm 2.0$
$n=0.57$	$n=1.72$	$n=0.44$
$n=1$	$n=2$	$n=1$

Though the results for both Cashier hours and Average wait time indicated that one (1) run would provide sufficient confidence for this experiment, this is somewhat misleading. A minimum of two (2) observations per test cell are actually needed to be able to use the t distribution. But since the calculation for Maximum wait time indicates two runs are necessary to achieve the desired confidence level for that variable, the issue becomes trivial and the analysis will be performed with two runs for each selected set of treatments.

VI. Results

This chapter will report the outcome of the research analysis described in the previous chapter. First and foremost, the examination of the Manpower Standard focuses upon the comparison of the three measurement groups defined in Chapter V. Within this context, each of the specific problems posed in Chapter I which addressed the Manpower Standard is resolved. Following this, the sensitivity analysis of the customer service system is profiled to include the resolution of the specific problems concerning the performance parameters and the regression models derived from the data produced by the simulation runs. Finally, a residual analysis is conducted for each model of interest. According to Gunst & Mason, "Examining residuals is one of the most important tasks in any regression analysis." (15:220) Each of the significant contributors to the analysis results is included in Appendix C.

Manpower Standard

As described in the last chapter, the manpower standard evaluation was broken into three computational groups: 1) OBHRS - actual, observed cashier hours documented during the Functional Review; 2) MSEXP & MSFR - cashier hours calculations using the proposed Manpower Standard which employ different arrival rates; and 3) LMEXP & LMFR - cashier hours calculations using CHOURS (p. 77) which employ the same arrival rates as MSEXP and MSFR.

LACKLAND AFB COMMISSARY

According to the AFCCMS Forms 28 which were used to record all labor observations during the Functional Review period (18 days), a total of 2419 hours were documented as checkstand-related cashier labor. This value is OBHRS. This was compared with the documented total of 5918 hours for the entire customer service department for a standard store-month. (3:4-16) A conversion for the second value was made ($5918 * 18/25.26 = 4217$) to standardize the data according to the 18-day data collection period. These two values (4217/2419) were placed into a ratio to determine a factor (1.743) which indicates the ratio of total customer service department hours to total cashier checkstand hours for the Functional Review data collection period. This ratio was also calculated for Rhein Main and turned out to be 1.784. A composite value (COMP) based upon the two ratios was set at 1.76 for any future calculations.

MSEXP was calculated using 68,235 customers, 25.26 operating days, and 222,692 coupons as expected input values for the proposed Manpower Standard. (3:4-21) This resulted in total hours of 6835. After applying the COMP ratio factor (1.76) and the conversion to 18 days of operation, the resultant value was 2767.

MSFR used 65,524 customers, 25.26 days, and 213,610 coupons. These inputs were based upon actual customer arrival rates during the Functional Review and a standard coupon/customer ratio of 3.26 for the Lackland AFB commissary. (3:4-21) The resultant value was 6574. The converted value was 2662.

LMEXP was calculated using 48,618 customers, 18 operating

days, a 3.04 minutes/transaction service rate (based upon observed data from the Functional Review), and a given LOS of 6 minutes average wait. This resulted in a value of 2890 hours. LMFR used 46,692 customers while holding the other values constant. This resulted in a value of 2792 cashier hours.

RHEIN MAIN AB COMMISSARY

Similar techniques were used in performing the manpower standard comparison for Rhein Main. The OBHRS were 938. The values used to calculate the two expected total parameters (MSEXP & LMEXP) were 38,044 customers, 20.91 operating days, and 30,298 coupons. (3:4-21) This set of values is based upon a full one-month operations period and was converted to correspond with the 15-day Functional Review period. The values used to calculate the two Functional Review-period parameters (MSFR & LMFR) were 36,258 customers, 20.91 days, and 28,643 coupons. In addition, the two Linear Model-related parameters used a 2.02 minutes/transaction factor as well as a 6-minute LOS setting in the final evaluations. As a result, the MSEXP was computed to be 1012 after adjustment to the 15-day observation period. The MSFR was 995. The LMEXP and the LMFR were 1202 and 1162, respectively. These results are listed in Table 9.

Table 9. Manpower Standard Evaluation Comparison

Measurement Parameter	LACKLAND	RHEIN MAIN
Observed Hours (OBHRS)	2419	938
Manpower Standard Predict		
- Expected (MSEXP)	2765	1012
- Observed in FR (MSFR)	2662	995
Linear Model Prediction		
- Expected (LMEXP)	2890	1202
- Observed in FR (LMFR)	2792	1162

COMPARISON ASSESSMENT

The first evidence which should be pointed out is that each scenario of the Manpower Standard-based model predicts more hours would be necessary to provide customer service prior to any LOS consideration for both stores. However, when LOS is accounted for by evaluating each of the two scenarios with the simulation-derived linear model, still more additional hours are required in both scenarios for Lackland and Rhein Main. This clearly indicates that other bases should be examined to determine if this pattern is consistent and that the Manpower Standard for Customer Service should be comprehensively re-evaluated. Under the conditions proposed by the Manpower Standard, Lackland could expect to have an average wait time of 13.2 minutes while Rhein Main could expect an average wait of over 27 minutes, well in excess of the desired maximum of 15 minutes. Interestingly, using the model developed for maximum waiting time (MYTIME) developed in the sensitivity

analysis, they each could expect a maximum wait of about 32 minutes for their patrons. This seems quite an endorsement for the use of a single service-queueing system.

Sensitivity Analysis

The first objective for this research effort was to determine the overall impact which the proposed Manpower Standard would have on the commissary customer service environment. Towards this end, the experimental design used for the sensitivity analysis was also used to develop a model for predicting necessary cashier labor while using Level-of-service as a factor in the development. That model, together with some additional information regarding its utility is presented first. With the first objective regarding the impact of the Manpower Standard satisfied, the task became the second objective: To determine the sensitivity of the customer service system performance parameters. Specifically, how will customer wait times be affected by variation in system operations factors such as customer arrivals and service times, and by variation in queueing-system configuration.

CASHIER HOURS

The regression equation (CHOURS) developed for the number of cashier hours had an $R^2 = .9873$, which means almost 99% of the variance can be explained by the regression relationship. Furthermore, the residual plot indicates the residuals are randomly distributed, indicating that no transformations or additional terms

are needed (32:326). The model is presented on page 76. In addition, the model for cashier hours provides a useful aid for estimating labor requirements for a given average wait time while allowing for variations in arrival rates and service time. Tables 10, 11, and 12 illustrate look-up tables for determining how many cashier hours would be necessary for a given day using an expected service time, an expected number of patrons, and a goal for average waiting time. The computer program developed to generate these tables is listed in Appendix D.

AVERAGE WAIT TIME

A model was developed to represent average wait time. However, the residual plot for the regression model was U-shaped. This shape disappeared, to some degree, when adding additional terms and/or using transformations. A logarithmic transformation of the CKOUT (checkout time) term showed the most improvement. But the residuals were still not random. Observations with WAIT (customer wait time) = 0.0 were removed from the data set because many of the data points created with this circumstance were actually negative values. This removed the left side of the "U", but the residual plot remained non-random. For this reason, the regression equation for wait time was not considered a valid predictor over the entire range of parameters considered and is not presented here.

MAXIMUM WAIT TIME

The regression equation for the maximum waiting time (MXTIME) had a lower R^2 ($=.6979$) than CHOURS. However, the plot of the residuals was random. It was considered a valid model and was used to calculate maximum wait times for the Manpower Standard evaluation.

LINEAR MODELS

The regression models for Cashier Hours and Maximum Wait Time are listed below and are valid over the following ranges:

Service-queue	Single, One-per-cashier
Checkout Time	1.67 to 3.47 (min)
Customers	1218 to 3390
Cashier Hours	59 to 196 (per day)

$$\begin{aligned} \text{CHRS} &= 23.0075 + 0.047743 (\text{CUSTLCK}) - 0.000359 (\text{CUSTXWT}) && \text{CHOURS} \\ \text{MAX} &= 26.998 - 1.164434 (\text{CHRS}) + 7.082697 (\text{QXCK}) \\ &\quad - 0.087953 (\text{QXCHRS}) + 0.020454 (\text{CUSTXCK}) && \text{MXTIME} \end{aligned}$$

where: CHRS = cashier hours
CKOUT = service time at the checkstand
MAX = maximum waiting time, 99th percentile customers
Q = service queue (1 for single, 2 for multiple)
WAIT = average customer waiting time
CUST = customers (arrivals less number balking)
CUSTLCK = CUST * LOG(CKOUT) (interaction term)
CUSTXWT = CUST * WAIT (interaction term)
QXCK = Q * CKOUT (interaction term)
QXCHRS = Q * CHRS (interaction term)

Table 10. Cashier Hours - 4 Minute Average Wait

Service Time	Customers						
	1200	1500	1800	2100	2400	2700	3000
1.75	53.3	60.9	68.5	76.1	83.7	91.3	98.9
2.00	61.0	70.5	80.0	89.5	99.0	108.5	118.0
2.25	67.7	78.9	90.1	101.3	112.5	123.7	134.8
2.50	73.8	86.5	99.2	111.9	124.6	137.2	149.9
2.75	79.2	93.3	107.4	121.4	135.5	149.5	163.6
3.00	84.2	99.5	114.8	130.1	145.4	160.7	176.1
3.25	88.8	105.3	121.7	138.2	154.6	171.1	187.5
3.50	93.1	110.6	128.1	145.6	163.1	180.6	198.1

Table 11. Cashier Hours - 8 Minute Average Wait

Service Time	Customers						
	1200	1500	1800	2100	2400	2700	3000
1.75	51.6	58.8	65.9	73.1	80.2	87.4	94.5
2.00	59.3	68.3	77.4	86.5	95.5	104.6	113.7
2.25	66.0	76.8	87.5	98.3	109.0	119.8	130.5
2.50	72.1	84.3	96.6	108.8	121.1	133.4	145.6
2.75	77.5	91.1	104.8	118.4	132.0	145.7	159.3
3.00	82.5	97.4	112.2	127.1	142.0	156.9	171.7
3.25	87.1	103.1	119.1	135.1	151.2	167.2	183.2
3.50	91.3	108.4	125.5	142.6	159.7	176.7	193.8

Table 12. Cashier Hours - 12 Minute Average Wait

Service Time	Customers						
	1200	1500	1800	2100	2400	2700	3000
1.75	49.9	56.6	63.3	70.1	76.8	83.5	90.2
2.00	57.5	66.2	74.8	83.5	92.1	100.7	109.4
2.25	64.3	74.6	84.9	95.3	105.6	115.9	126.2
2.50	70.3	82.2	94.0	105.8	117.7	129.5	141.3
2.75	75.8	89.0	102.2	115.4	128.6	141.8	155.0
3.00	80.8	95.2	109.7	124.1	138.6	153.0	167.4
3.25	85.4	101.0	116.5	132.1	147.7	163.3	178.9
3.50	89.6	106.3	122.9	139.6	156.2	172.9	189.5

VARIATIONS IN ARRIVALS AND SERVICE

In order to accurately schedule cashiers, it is necessary to predict the number of arrivals both by day and by hour. AFCOMS has performed analyses of this type at the daily-sales-level. But the hourly-sales-level has not received the attention necessary to be of real service to the store managers.

Service time, as has been previously discussed, is quite difficult to analyze and predict. There are at least four separate factors which will each influence the length of a transaction (coupons, items, payment medium, and cashier) and may be others.

Pattern Analysis

The data used to evaluate this portion of the study was the Functional Review data from Lackland and Rhein Main. There was one major holiday during each of the observation periods, each holiday coinciding with a payday, so it is difficult to tell if the increase in customers and service time is due to the holiday or the payday. In addition, each of the four military paydays during the two data collection periods fell on a Friday. This created a considerable bias within customer arrival patterns for these four days as well as those days close to payday. More study of hourly operations is necessary with a wider range of store location, payday variance, and holiday impact taken into account.

However, the available data from the Functional Review was used to perform a thorough analysis. The number of busy hours for the cashiers was summarized from Functional Review documentation

(AFCOMS Forms 28). The methodology demonstration (or quick analysis) is shown in Appendix E. Another factor in scheduling cashiers is the pattern of arrivals. Appendix E also contains a brief analysis and discussion on the pattern of arrivals.

Impact of Variation in Arrival Rate

The simulation model was run using random draws for customer arrivals (for each hour) and service time (for each customer). Table 13 illustrates the resultant waiting times for a range of variations in customer arrivals based on a given number of cashier hours and a given service rate for each base.

Table 13. Change in Waiting Time Due to Changes in Customer Arrivals				
Change in Customer Arrivals	-5%	0	+5%	+10%
Lackland (2500 customers) (with 151.2 hours scheduled)	0.0	5.0	11.8	18.0
Rhein Mein (2000 customers) (with 86.6 hours scheduled)	1.2	5.0	9.2	13.0

As indicated in Table 13, a five percent reduction in customer arrivals would reduce the average wait to zero minutes (or close to it) in both cases (causing a reduction in cashier utilization), whereas a five percent increase in customers would double the expected wait.

Impact of Variation in Service Rate

Table 14 illustrates the resultant waiting times for a

variation in service times with a given level of cashier hours and customers served. As Table 14 indicates, a five percent decrease in the average service time will reduce the average wait to zero, which in turn will cause reduced cashier utilization. An increase in the average service time of five percent would cause wait times to more than double.

Table 14. Change in Waiting Time Due to Changes in Customer Service Time				
Change in Service Time	-5%	0	+5%	+10%
Lackland (2500 customers) (with 151.2 hours scheduled)	0.0	5.0	11.5	17.7
Rhein Mein (2000 customers) (with 86.6 hours scheduled)	0.0	5.0	11.4	17.6

Truly, a delicate balance is maintained between short waiting periods and busy employees. When small variations in either factor are encountered, large impacts are felt. And in an era of increased fiscal restrictions, maximum use of all resources must remain a high priority while not discouraging people from using the benefit. We must use all available tools to improve predictions for the customer arrivals and service times for each day.

QUEUEING CONFIGURATION

The regression model derived for maximum wait time is highly influenced by the system service-queue configuration. The model contains two interaction terms which include service-queue as one of the factors. To no surprise, this clearly indicates that all

stores ought to incorporate a single-service-queue system unless the physical store layout would prohibit it. To evaluate the change in maximum wait due to the service-queue configuration, the first derivative of MXTIME (maximum wait time) with respect to Q (service-queue) is calculated. To determine the range of impact, the remaining factors are held at the low and high values. Since the coefficient of CHRS is negative, the low-end value occurs at high cashier hours. Table 15 displays the increase in maximum wait time attributed to a multiple service-queue system.

$$\frac{d(\text{MAX})}{d(Q)} = 7.0827 (\text{CKOUT}) - 0.0880 (\text{CHRS}) \quad \text{QEVAL}$$

Table 15. Changes in Maximum Wait
Due to Multiple Service-Queues (Min)

Arrival Rate	Rhein Main Lackland	
	low	+3.4
	high	+11.6

Within the context of the observed stores, the maximum waiting time increases under all arrival conditions. This adds further credence to the idea that single-service-queue systems should be employed where permitted. Although the average wait time does not differ substantially for single vs. multiple-queue systems, some portion of the customers at each store can expect their waiting time to increase by as much as **12 minutes** due to a choice of the "wrong" line in a multiple-line system. Clearly, the single service-queue configuration is a much **fairer** system.

VII. Conclusions and Recommendations

This chapter summarizes the results of the research and includes commentary pertinent to the results. It also includes a series of recommendations for extending the research accomplished in this effort.

Specific Problem Conclusions

1) How do the cashier manpower requirements calculated by the proposed AFCOMS Manpower Standard compare with those determined by the simulation analysis?

For both Lackland and Rhein Mein, the Modified GPCSS indicated more hours were needed to meet the AFCOMS service goal than would be provided under the proposed Manpower Standard. At Lackland, the proposed Manpower Standard would have allowed an average of 153.7 hours for manning the cashier stands for an average day where the simulation-derived model would have provided 165.4 hours, an increase of nearly 8%. At Rhein Mein, the proposed standard would have allowed an average of 67.5 hours per day while the linear model would have provided 83.4 hours, a difference of more than 23% more labor! Since each of the linear model calculations uses a 6-minute waiting time LOS, the lower labor allocations would no doubt have a substantial impact on customer waiting times.

2) What are the expected mean and maximum waiting times in the commissary given the proposed Manpower Standard?

Using the above figures regarding cashier labor, the simulation model indicated that conditions at the Lackland commissary would result in average waits of about 13 minutes, a higher value than store management would normally prefer. As a result, the maximum wait would increase to **32 minutes!** However, the cashier hours allocated for Rhein Main based on the Manpower Standard would result in queueing conditions where patrons could expect average waits of **27.2 minutes**, an extremely unsatisfactory situation! However, because Rhein Main uses a single-line service-queue, the maximum wait would increase much less than Lackland. It would grow to about 32 minutes, the same as Lackland.

3) How sensitive are customer waiting time performance measures to changes in customer arrival patterns and variations in service rates and to service-system queueing configuration?

Average wait time is quite sensitive to both customer arrival variations as well as changes in service time. Small increases or decreases in either parameter trigger significantly longer or shorter wait times for commissary patrons.

Recommendations for Future Analysis

Three areas which warrant more analysis are: estimating arrival rates and service times for each day (and each hour if possible), identifying distributions and factors affecting service time, and examining the impact of varying managerial control.

Additional stores would also be useful for further analysis to clarify the relationships developed by this effort. An assessment of whether or not the cashier hours linear model would apply to other stores would be quite useful.

Further review of the current model-building process for manpower standards might be an extremely fertile area for analysis, not only for AFCOMS, but for the entire Department of Defense. In light of current conditions, DOD-wide manpower standards may be changing tremendously in the next few years. One thing very clear about the current procedures which create manpower standards: The regression models are **NOT** as good as they can be. Because of the lack of flexibility within the system to recognize the utility of complex models which contain "unusual" terms (interaction, negative, quadratic, etc.), the manpower employment standards being incorporated are not as accurate as they should be. Upper-level managers must realize that the accuracy of such a linear model is of greater importance than intuitive justification for each of its component factors. The end product is the ultimate "yardstick" of a model's accuracy, not its composition.

APPENDIX A. SIMULATION MODEL

SLAM Network.....	89
FORTTRAN Program.....	95

MODIFIED GENERAL PURPOSE COMMISSARY STORE SIMULATION (MGPCSS) SLAM NETWORK

```

GEN,FRITZ,COMM,10/01/89,1,,N,,N,N,72;ilist,iecho,ixqt,ipirh,ismry
LIMITS,41,4,700;
INIT,0.0,605.0; minutes opens
INTLC,XX(3)=8.0,XX(12)=1,XX(14)=0;
INTLC,XX(4)=.1,XX(5)=3.04,XX(7)=3,XX(9)=175,XX(10)=200,XX(11)=225;
INTLC,XX(17)=900,XX(18)=1900,XX(19)=21,XX(20)=21,XX(22)=23.0;
INTLC,XX(25)=1.0,XX(26)=2.00,XX(27)=3.92,XX(28)=4.68,XX(29)=5.75;
INTLC,XX(30)=5.67,XX(31)=5.57,XX(32)=5.63,XX(33)=5.10,XX(34)=5.25;
INTLC,XX(35)=2.15,XX(36)=0.00,XX(37)=0.00;
INTLC,XX(40)=0.60,XX(41)=0.167,XX(42)=3.26;
INTLC,XX(50)=1.0,XX(51)=3,XX(52)=7,XX(53)=8,XX(54)=12,XX(55)=14;
INTLC,XX(56)=16,XX(57)=17,XX(58)=17,XX(59)=17,XX(60)=18,XX(61)=18;
INTLC,XX(62)=18,XX(63)=18,XX(64)=18,XX(65)=18,XX(66)=18,XX(67)=18;
INTLC,XX(68)=18,XX(69)=18,XX(70)=15,XX(71)=0;
NETWORK;
;
; VARIABLES
; 1 - minutes store is open, calculated in FORTRAN
; 2 - shopping time
; 3 - waiting time to add cashier
; 4 - % express customers
; 5 - mean checkout time
; 6 - # customers in store
; 7 - time interval for status check
; 8 - congestion factor (=1.0 at start, calc in FORTRAN)
; 9 to 11 - congestion values (9=low,10=medium,11=high)
; 12 - day #, used to identify output (range 1 to 99)
; 13 - waiting time for the current status check interval
; 14 - arrival rate code, used when using max. cashiers by hour
;      (8: 8% above expected, 0: as expected, -2: 2% below expected)
; 15 - current time between arrivals x 2
; 16 - used in calc for express time
; 17 - opening time
; 18 - closing time
; 19 - # of checkstands
; 20 - # of queues (choices are 1, 2, or # of checkstands)
; 21 - ratio of customers in line to cashiers (used for balking)
; 22 - shopping time (15 min. for RheinMain, 23 min. for Lackland)
; 23 - checkout time for express (function of mean checkout)
; 24 - checkout time for regular (function of mean checkout)
; 25 - code (0 will for arrival rates; otherwise, input)
; 26 to 39 - hourly arrival rates
; 40 - % of customers using coupons
; 41 - time (in minutes) to process one coupon
; 42 - coupons per customer (=3.26 for Lackland,.796 for RheinMain)
; 43 - checkout time, randomly assigned in event 13
; 50 - code (0: allocates max. cashiers by hour; otherwise - input)
; 51- 98 - maximum cashiers. bv 1/2 hour

```

```

;
; ATTRIBUTES
; 1 - not used
; 2 - # items purchased
; 3 - # carts
; 4 - time arrived in checkout line
;
; Parking spots, shopping carts, baggers, and cashiers are all
;treated as resources.
;
RESOURCE/1,PARK(400),1; PARKING LOT
RESOURCE/2,SMAL(50),5; SMALL SHOPPING CARTS
RESOURCE/3,LRGE(350),4; LARGE SHOPPING CARTS
RESOURCE/4,XCASH(1),6; CASHIERS FOR EXPRESS LINES
RESOURCE/5,CASH1(0),7; Cashiers for Queue 1
RESOURCE/6,CASH2(0),8; Cashiers for Queue 2
RESOURCE/7,CASH3(0),9; Cashiers for Queue 3
RESOURCE/8,CASH4(0),10; Cashiers for Queue 4
RESOURCE/9,CASH5(0),11; Cashiers for Queue 5
RESOURCE/10,CASH6(0),12; Cashiers for Queue 6
RESOURCE/11,CASH7(0),13; Cashiers for Queue 7
RESOURCE/12,CASH8(0),14; Cashiers for Queue 8
RESOURCE/13,CASH9(0),15; Cashiers for Queue 9
RESOURCE/14,CASH10(0),16; Cashiers for Queue 10
RESOURCE/15,CASH11(0),17; Cashiers for Queue 11
RESOURCE/16,CASH12(0),18; Cashiers for Queue 12
RESOURCE/17,CASH13(0),19; Cashiers for Queue 13
RESOURCE/18,CASH14(0),20; Cashiers for Queue 14
RESOURCE/19,CASH15(0),21; Cashiers for Queue 15
RESOURCE/20,CASH16(0),22; Cashiers for Queue 16
RESOURCE/21,CASH17(0),23; Cashiers for Queue 17
RESOURCE/22,CASH18(0),24; Cashiers for Queue 18
RESOURCE/23,CASH19(0),25; Cashiers for Queue 19
RESOURCE/24,CASH20(0),26; Cashiers for Queue 20
RESOURCE/25,CASH21(0),27; Cashiers for Queue 21
RESOURCE/26,CASH22(0),28; Cashiers for Queue 22
RESOURCE/27,CASH23(0),29; Cashiers for Queue 23
RESOURCE/28,CASH24(0),30; Cashiers for Queue 24
RESOURCE/29,CASH25(0),31; Cashiers for Queue 25
RESOURCE/30,CASH26(0),32; Cashiers for Queue 26
RESOURCE/31,CASH27(0),33; Cashiers for Queue 27
RESOURCE/32,CASH28(0),34; Cashiers for Queue 28
RESOURCE/33,CASH29(0),35; Cashiers for Queue 29
RESOURCE/34,CASH30(0),36; Cashiers for Queue 30
RESOURCE/35,CASH31(0),37; Cashiers for Queue 31
RESOURCE/36,CASH32(0),38; Cashiers for Queue 32
RESOURCE/37,CASH33(0),39; Cashiers for Queue 33
RESOURCE/38,CASH34(0),40; Cashiers for Queue 34
RESOURCE/39,CASH35(0),41; Cashiers for Queue 35
RES/40,BAG(100),7,8,9,10,11,12,13,14,15,16,17,18,19,20,
23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,
38,39,40,41;

```

```

STRT  CREATE,,.1,1,,1;
      ACT,,TNOW.LE.XX(1),DOOR;
      ACT,,TNOW.GT.XX(1);
      EVENT,3,1;
      TERM;
DOOR  GOON;
      ACT,EXP(XX(15),1),,STRT;
      ACT/1;
PKNG  AWAIT(1/10),PARK/1,BALK(LEV1); WAIT FOR PARKING
      ACT/2,,LOOK;
LEV1  GOON; BALK AND LEAVE IF PARKING LOT TOO FULL
      ACT/90;
      COLCT(1),INT(1),PARK BALKS,,1;
      TERM;
LOOK  GOON,1; 20% balk if > 8 customers/cashier
      ACT/89,,XX(21).GT.8.0,LEV3;
;      ACT/88,,XX(21).GT.12.0,LEV4;
      ACT,,DESK;
LEV3  GOON,1;
      ACT,,.80,DESK;
      ACT/91,,FRPK;
LEV4  GOON,1;
      ACT,,.70,DESK; 30% balk if >12
      ACT/92,,FRPK;
DESK  QUEUE(2),0,99,BALK(LEV2); I.D. DESK
      ACT/3,.1,,CONT;
LEV2  FREE,PARK/1,1; BALK AND LEAVE IF LINE AT DESK TOO LONG
TERM  TERM;
CONT  GOON,1;
      ACT/4,0.6,.70; CHECK WRITING CUSTOMERS
      ACT/5,,.30; CASH CUSTOMERS
CART  GOON,1;
      ACT/7,.1,XX(4),XPRS; EXPRESS CUSTOMERS
      ACT/8,.1,1-XX(4),REG; REGULAR CUSTOMERS
XPRS  ASSIGN,TRIB(2)=UNFRM(1.0,XX(22),1),XX(2)=EXP(4.0,1),1;
      AWAIT(5),SMAL/1,BLOCK,1;
      ACT/9,XX(2),,XLIN;
REG  EVENT,11,1; Event 11 assigns #items, shopping time: xx(2)
      AWAIT(4/20),LRGE/TRIB(3),BALK(LEVC),1;
      ACT/10,XX(2),,SELQ;
LEV3  FREE,PARK/1,1; LEAVE IF LINE FOR CARTS TOO LONG
      ACT/93,,TERM;
;
;      THIS PART OF THE NETWORK SIMULATES EXPRESS LINE CHECKOUT.
;
XLIN  AWAIT(6),XCASH;
      ACT/11,EXP(XX(23),2);
      FREE,SMAL/1,1;
      ACT,.1;
      FREE,XCASH/1,1;
      ACT/12,2.0,,FRPK;

```

```

;   THIS PART OF THE NETWORK SIMULATES THE REGULAR QUEUE LINES.
;
SELQ  EVENT,1,1; Selects the shortest queue
      TERM;
LIN1  AWAIT(7),ALLOC(1),2; Line 1 Queue
      ACT,,,EV13; calculates wait time, assign checkout time
      ACT/13,XX(43); Checkout time
      FREE,CASH1/1,1;
      ACT,,,FRBG;
LIN2  AWAIT(8),ALLOC(2);LINE 2 Queue
      ACT,,,EV13;
      ACT/15,XX(43); Checkout time
      FREE,CASH2/1,1;
      ACT,,,FRBG;
LIN3  AWAIT(9),ALLOC(3);LINE 3 Queue
      ACT,,,EV13;
      ACT/17,XX(43);
      FREE,CASH3/1,1;
      ACT,,,FRBG;
LIN4  AWAIT(10),ALLOC(4),2; Line 4 Queue
      ACT/19,XX(43);
      ACT,,,EV13;
      FREE,CASH4/1,1;
      ACT,,,FRBG;
LIN5  AWAIT(11),ALLOC(5),2; Line 5 Queue
      ACT/21,XX(43);
      ACT,,,EV13;
      FREE,CASH5/1,1;
      ACT,,,FRBG;
LIN6  AWAIT(12),ALLOC(6),2; Line 6 Queue
      ACT/23,XX(43);
      ACT,,,EV13;
      FREE,CASH6/1,1;
      ACT,,,FRBG;
LIN7  AWAIT(13),ALLOC(7),2; Line 7 Queue
      ACT/25,XX(43);
      ACT,,,EV13;
      FREE,CASH7/1,1;
      ACT,,,FRBG;
LIN8  AWAIT(14),ALLOC(8),2; Line 8 Queue
      ACT/27,XX(43);
      ACT,,,EV13;
      FREE,CASH8/1,1;
      ACT,,,FRBG;
LIN9  AWAIT(15),ALLOC(9),2; Line 9 Queue
      ACT/29,XX(43);
      ACT,,,EV13;
      FREE,CASH9/1,1;
      ACT,,,FRBG;
LI10  AWAIT(16),ALLOC(10),2; Line 10 Queue
      ACT/31,XX(43);
      ACT,,,EV13;

```

```

FREE,CASH10/1,1;
ACT,,,FRBG;
LI11  AWAIT(17),ALLOC(11),2; Line 11 Queue
      ACT/33,XX(43);
      ACT,,,EV13;
      FREE,CASH11/1,1;
      ACT,,,FRBG;
LI12  AWAIT(18),ALLOC(12),2; Line 12 Queue
      ACT/35,XX(43);
      ACT,,,EV13;
      FREE,CASH12/1,1;
      ACT,,,FRBG;
LI13  AWAIT(19),ALLOC(13),2; Line 13 Queue
      ACT/37,XX(43);
      ACT,,,EV13;
      FREE,CASH13/1,1;
      ACT,,,FRBG;
LI14  AWAIT(20),ALLOC(14),2; Line 14 Queue
      ACT/39,XX(43);
      ACT,,,EV13;
      FREE,CASH14/1,1;
      ACT,,,FRBG;
LI15  AWAIT(21),ALLOC(15),2; Line 15 Queue
      ACT/41,XX(43);
      ACT,,,EV13;
      FREE,CASH15/1,1;
      ACT,,,FRBG;
LI16  AWAIT(22),ALLOC(16),2; Line 16 Queue
      ACT/43,XX(43);
      ACT,,,EV13;
      FREE,CASH16/1,1;
      ACT,,,FRBG;
LI17  AWAIT(23),ALLOC(17),2; Line 17 Queue
      ACT/45,XX(43);
      ACT,,,EV13;
      FREE,CASH17/1,1;
      ACT,,,FRBG;
LI18  AWAIT(24),ALLOC(18),2; Line 18 Queue
      ACT/47,XX(43);
      ACT,,,EV13;
      FREE,CASH18/1,1;
      ACT,,,FRBG;
LI19  AWAIT(25),ALLOC(19),2; Line 19 Queue
      ACT/49,XX(43);
      ACT,,,EV13;
      FREE,CASH19/1,1;
      ACT,,,FRBG;
LI20  AWAIT(26),ALLOC(20),2; Line 20 Queue
      ACT/51,XX(43);
      ACT,,,EV13;
      FREE,CASH20/1,1;
      ACT,,,FRBG;

```



```

LI21  AWAIT(27),ALLOC(21),2; Line 21 Queue
      ACT/53,XX(43);
      ACT,,,EV13;
      FREE,CASH21/1,1;
      ACT,,,FRBG;
LI22  AWAIT(28),ALLOC(22),2; Line 22 Queue
      ACT/55,XX(43);
      ACT,,,EV13;
      FREE,CASH22/1,1;
      ACT,,,FRBG;
; can add additional queue lines up to 35, by changing
; the following:
;   LI**, AWAIT(**),ACT/**,ALLOC(**),CASH**; to maximum values:
;   LI35, AWAIT(41),ACT/81,ALLOC(35),CASH35;
EV13  EVENT,13,1; Event 13 calculates wait time
      FREE,LRGE/ATRIB(3),1;
      TERM;
FRBG  GOON,1;
      ACT/82,EXP(2.2,3); Transit time for bagger
      FREE,BAG/1,1;
      ACT;
FRPK  FREE,PARK/1,1;
      TERM;
      END;
SEEDS,4382381(1)/NO,8532327(2)/NO,1952779(3)/NO;
SIMULATE;
FIN;

```

MGPCSS SLAM FORTRAN PROGRAM

\$INCLUDE: 'PRCTL.FOR'

* This is the FORTRAN interface with the SLAM EXECUTIVE. All
* subroutines are used for interfacing with the user or for
* changing model resources during execution of the Simulation.

```

PROGRAM MAIN
COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP
1,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT
1,TNOW,XX(100)
NCRDR=5
NPRNT=0
NTAPE=7
CALL SLAM
STOP ' '
END

```

SUBROUTINE ALLOC(I,IFLAG)

* This Subroutine allocates resources, i.e. cashiers and baggers
* to serve customers that have finished shopping.

```

COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP
1,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT
1,TNOW,XX(100)
IFLAG=0

```

```

* need both cashier and bagger
IF(NNRSC(40).LE.0.OR.NNRSC(I+4).LE.0)RETURN
CALL SEIZE(40,1)
CALL SEIZE(I+4,1)
IFLAG=-1
RETURN
END

```

SUBROUTINE INTLC

```

COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP
1,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT
1,TNOW,XX(100)
COMMON/USER1/NQUE,NOPT,NSTAND(38),NSTRT(38),NQUSE,C(38),CKOUTO
CALL SCHDL(2,XX(7),ATTRIB)
CALL SCHDL(5,XX(7),ATTRIB)
CALL SCHDL(4,.001,ATTRIB)
call schdl(9,60.0,atrib)
call schdl(7,30.01,atrib)
XX(8)=1.0

```

*** set current time between arrivals

xx(15)=1.0/xx(26)

*** calculate checkout times for express and regular (from mean)

xx(23)=0.25*xx(5)

```

      xx(24)=(xx(5)-xx(4)*xx(23))/(1-xx(4))
*** calculate checkout time without coupons
      ckout0=xx(24)-(xx(41)*xx(42))
      write(3,*)' avg,exp,reg,nocoupon=',xx(5),xx(23),xx(24),ckout0
      if(nnrun.eq.1)then
        write(4,*)'          max max          ck add %    ckr total util
1 max      avg      std'
        write(4,*)' day ckr qs arvl #exp #gen out ckr balk use hrs rate
1wait      wait      wait +15'
      endif
*****
      nwait=0
      nquse=int(xx(20))
      nopen=int(xx(17))
      nclose=int(xx(18))
*****
      IDIFF=((NCLOSE-NOPEN)/100)*100
      DIFF=REAL(NCLOSE)-REAL(NOPEN)
      xx(1)=real((nclose-nopen)/100*60)+(diff-idiff)
      nend=(nclose-nopen)/100
      if(real(idiff).ne.diff) nend=nend+1
      write(3,*)' minutes open (xx1)=' , xx(1)
*** assign checkstands to queues
      if(xx(19).eq.xx(20)) then
        do 53 i=1,nquse
53      nstand(i)=1
        elseif (xx(20).eq.1) then
          nstand(1)=int(xx(19))
        elseif (xx(20).eq.2) then
          nstand(1)=0.5*xx(19)
          nstand(2)=xx(19)-nstand(1)
        else
          write(*,*)' error in assigning stands to queues, chg FORTRAN'
          stop
        endif
      nque=1
      nstrt(1)=1
      ii=nstrt(1)
*** maximum cashiers per 1/2 hour calc.if xx(50)=0; else, input
      if(xx(50).ne.0.and.xx(19).eq.xx(20)) then
        nquse=xx(51)-1
        elseif(xx(50).ne.0.and.xx(20).eq.1) then
          nstand(1)=xx(51)-1
        elseif(xx(50).ne.0.and.xx(20).eq.2) then
          nstand(1)=xx(51)*0.5
          nstand(2)=xx(51)-nstand(1)-1
        endif
*****
10      continue
      WRITE(3,999)NBAG,NQUSE,NWAIT,NOPEN,NCLOSE
      WRITE(3,998)NQUE
099      format(5(1x,i4/))

```

```

998  FORMAT(' #queues at opening=',I2)
      DO 75 I=1,NQUSE
75    WRITE(3,997)I,NSTAND(I)
      DO 80 I=1,NQUE
80    WRITE(3,996)I,NSTRT(I)
996  format(' Queue#',I2,' has ',i2,' checkstands open')
997  format(' Queue#',i3,' is serviced by',i2,' checkstands')
      K=1
      if(xx(25).eq.0) then
        DO 310 I=NOOPEN,NCLOSE-100,100
          WRITE(*,320)I,I+100
          WRITE(*,'(A\)'')' Enter customer arrival rate -----> '
          READ(*,*)C(K)
          K=K+1
310   CONTINUE
          IF(real(idiff).ne.diff)THEN
            WRITE(*,320)I,NCLOSE
            WRITE(*,'(A\)'')' Enter customer arrival rate -----> '
            READ(*,*)C(K)
          ENDIF
        else
          xfactr=1+xx(14)/100
          do 315 i=1,nend
315    c(i)=xx(25+i)*xfactr
          endif
320   FORMAT(1X,I4,' Hrs To ',I4,' Hrs :')
      WRITE(3,994)
994   FORMAT(' ARRIVAL RATE PER MINUTE')
      DO 70 I=1,NEND
70    WRITE(3,992)C(I)
992   FORMAT(12X,F6.4)
*****
Appropriate calls are made to alter resources.
      DO 60 K=1,NWAIT
        ATRIB(1)=0.0
        CALL FILEM(2,ATRIB)
60    CONTINUE
        CALL SEIZE(1,NWAIT)
        DO 13 I=5,NQUE+4
13    CALL ALTER(I,NSTRT(I-4))
        CALL ALTER(40,3)
        WRITE(*,*)'Simulation Begins ...'
        WRITE(*,*)' '
        RETURN
      END

      SUBROUTINE EVENT(I)
*****
*    Event    Description
*      1      Finds the shortest queue for customer.
*      2      Opens and closes checkstands/queues as needed.
*      3      Ends simulation at time xx(1).

```

```

*      4      Status check - # in store, #cashiers.
*      5      Opens or closes an express line.
*      6      Allows customer to move to shorter queue - jockeying.
*      7      Hourly changes - maximum cashiers, arrival rate.
*      8      Used to make sure closed queue is empty.
*      9      Allows customer to move to shorter queue.
*     10      not used
*     11      Assigns the # of items each customer buys. If items>100,
*              the customer will need 2 carts. Attribute 3 = # of carts.
*     12      not used
*     13      Calculates waiting time, checkout time.
*****

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON/USER1/NQUE,NOPT,NSTAND(38),NSTRT(38),NQUSE,C(38),CKOUT0
common/out1/ncash(1200),nobs,nexp,wtmax,maxckr,cash0,plus15
common/out2/ckavg,ztot,ncount,twait(5000)
data cash1,cash2,ix,tlast/0.0,0.0,1,60.0/
GO TO(1,2,3,4,5,6,7,8,9,10,11,12,13)I
*****

1      continue
*** expected wait for shortest queue, assign time wait started: atrib4
      expwt0=99999.0
      DO 30 J=7,NQUE+6
          expwt= (NNQ(J))/((NNRSC(J-2)+NRUSE(J-2))*(1.0/XX(24)))
          IF(expwt.LT.expwt0)THEN
              NSHORT=J
              expwt0=expwt
          ENDIF
30     CONTINUE
      atrib(4)=tnow
      CALL FILEM(NSHORT,ATRIB)
      RETURN

*****

2      IF(TNOW.LT.XX(1))CALL SCHDL(2,XX(7),ATRIB)
*** if expected wait>xx3 (add cashier interval), try open checkstand
      IWAIT=0
      IALT=0
      if(expwt0.gt.xx(3))then
          iwait=1
          DO 20 I=5,NQUE+4
              IF(NNRSC(I)+NRUSE(I).LT.NSTAND(I-4))THEN
                  IALT=1
                  CALL ALTER(I,1)
                  CALL ALTER(40,3)
                  go to 22
              ENDIF
20     CONTINUE
      endif
22     continue

```

```

*** if cannot open checkstand, try to open another queue
    IF(iwait.eq.1.and.IALT.NE.1.and.nque.lt.nquse)THEN
        IF(NNRSC(NQUE+5)+NRUSE(NQUE+5).LT.NSTAND(NQUE+1))THEN
            NQUE=NQUE+1
            CALL ALTER(NQUE+4,1)
            CALL ALTER(40,3)
            ialt=1
        ENDIF
    ENDIF
    if (ialt.eq.1) call schdl(6,.001,atrib)
*** can cashier or queue be removed?
    if(xx(ix+50).ge.ii.and.xx(50).ne.0)return
    if(tnow.le.tlast+xx(7).or.expwt0.gt.3.0)return
    DO 45 J=NQUE+4,5,-1
        WAIT=(NNQ(J+2))/((NNRSC(J)+NRUSE(J))*(1.0/XX(5)))
        IF(WAIT.LT.3.0.AND.II.GT.3)THEN
            IF(NNRSC(J)+NRUSE(J).EQ.1.AND.NNQ(J+2).EQ.0)THEN
                NQUE=NQUE-1
                CALL ALTER(NQUE+5,-1)
                CALL ALTER(40,-3)
                call schdl(8,0.2,atrib)
                tlast=tnow
            elseif(nnrsc(j)+nruse(j).gt.1)then
                CALL ALTER(J,-1)
                CALL ALTER(40,-3)
                tlast=tnow
            ENDIF
        ENDIF
*** if #cashiers = #queues, can only delete last queue
        SUM=0.0
        DO 47 LL=5,NQUE+4
47          SUM=SUM+NNRSC(LL)+NRUSE(LL)
            IF(NQUE.EQ.INT(SUM))return
        ENDIF
45    CONTINUE
    RETURN

```

```

*****
3      WRITE(*,*)' '
        nexp=0
        do 910 i=1,24
910    nexp=nexp+(c(i)*60)
        ix=1
        tlast=0.0
        call sumout
        RETURN

```

```

*****
4      CALL SCHDL(4,XX(7),ATRIB)
*** schedule jockeying
        call schdl(6,0.01,atrib)
*** calc. # in store
        NIS=0

```

```

DO 33 J=7,NQUE+6
33  NIS=NIS+NNQ(J)
DO 14 J=1,82
14  NIS=NIS+NNACT(J)
    XX(6)=REAL(NIS)
*** assign congestion factor
    if(xx(6).gt.xx(9)) xx(8)=1.1
    if(xx(6).gt.xx(10)) xx(8)=1.2
    if(xx(6).gt.xx(11)) xx(8)=1.4
    if(xx(6).le.xx(9)) xx(8)=1.0
*** current cashiers, ii; utilization of regular cashiers
* cashiers, cash2; #used, cash1; cumulative utilization rate, cash0
    ii=nnrsc(4)+nruse(4)
    if(tnow.lt.15.0) then
        cash1=0.0
        cash2=0.0
    endif
    if(tnow.gt.15.0) then
        DO 55 J=1,NQUE
            ii=ii+nruse(j+4)+nnrsc(j+4)
            cash2=cash2+nruse(j+4)+nnrsc(j+4)
            cash1=cash1+nruse(j+4)
55      continue
        if(cash2.gt.0) cash0=cash1/cash2
    endif
    if(ii.gt.maxckr) maxckr=ii
    itime=1+int(tnow/60.0)
    nobs=nobs+1
    ncash(nobs)=ii
*** calc. ratio of customers to cashiers
    nline=0
    do 210 i=6,41
210   nline=nline+nnq(i)
        if(ii.ge.1) xx(21)=nline/ncash(nobs)
        if(ii.eq.0) xx(21)=0.0
*** print status
    if(ntitle.eq.0) then
        write(3,*) ' Hour Total Cust. # in Store #Cashiers ExpdWait'
        write(*,*) ' Hour Total Cust. Current #Cashiers ExpdWait'
    endif
    ntitle=1
    WRITE(*,100) ITIME,nncnt(1),NIS,II,expwt0
    write(3,100) itime,nncnt(1),nis,ii,expwt0
100   FORMAT(3X,I2,6X,i4,6X,I4,6X,i2,6X,f6.2)
    RETURN

*****
5   IF(TNOW.LT.XX(1))CALL SCHDL(5,XX(7),ATTRIB)
    WAIT=(NNQ(6))/((NNRSC(4)+NRUSE(4))*(1.0/xx(23)))
*** can change # of express cashiers if not changed in last 15 min.
    IF(tnow-expchg.GE.15.0)THEN
        IF(WAIT.GT.5.0.AND.NNRSC(4)+NRUSE(4).LT.2)CALL ALTER(4,1)

```

```

        IF(WAIT.LT.2.0.AND.NNRSC(4)+NRUSE(4).EQ.2)CALL ALTER(4,-1)
        expchg=tnow
    ENDIF
    RETURN

```

```

*****

```

```

6    if(nque.eq.1) return
*** moves customer in a long queue to shorter queue
65   nempty=0
      wtlong=0.0
      nlong=0
      do 60 i=7,nque+6
        expwt=(nnq(i))/((nnrsc(i-2)+nruse(i-2))*(1.0/xx(24)))
        if (expwt.le.5.0) then
          nempty=i
          wtshrt=expwt
        endif
        if (expwt.gt.10.0.and.expwt.gt.wtlong) then
          nlong=i
          wtlong=expwt
        endif
60    continue
*** find the customer, at least 2nd in queue
      if(nempty.ne.0.and.nlong.ne.0) then
        if(nnq(nlong).lt.3) write(3,*)' error, in jockeying'
        if(wtshrt.eq.0) call rmove(2,nlong,atrib)
        if(wtshrt.gt.0) call rmove(3,nlong,atrib)
        call filem(nempty,atrib)
        call schdl(6,0.1,atrib)
        write(3,*)' jockeying'
      endif
      return

```

```

*****

```

```

7    if(tnow.ge.xx(1)) return
      write(*,*)tnow,' run#',nnrun
      ihour=1+tnow/60.0
      xx(15)=1.0/c(ihour)
      call schdl(7,30.0,atrib)
*** maximum cashiers and/or queues, leave out 1 for express
      if(xx(50).eq.0) return
      ix=ix+1
      if(xx(19).eq.xx(20)) then
        nquse=xx(50+ix)-1
        ndiff=nquse-nque
        if(ndiff.gt.0) then
          do 75 i=1,ndiff
            nque=nque+1
            call alter(nque+4,1)
            call alter(40,3)
            call schdl(6,.001,atrib)
75      continue

```



```

        endif
    elseif (xx(20).eq.1) then
        nstand(1)=xx(50+ix)-1
        nold=nnrsc(5)+nruse(5)
        ndiff=nstand(1)-nold
        ndiff1=3*ndiff
        if(ndiff.gt.0) call alter(5,ndiff)
        if(ndiff.gt.0) call alter(40,ndiff1)
    elseif(xx(20).eq.2) then
        nstand(1)=xx(50+ix)*0.5
        nstand(2)=xx(50+ix)-nstand(1)-1
        write(*,*)' model not finished, event 7'
        stop
    endif
    return
*****
8      do 80 j=nque+7,41
        if(nnq(j).gt.0) then
            write(3,*)' customer in closed queue',j-6
            call rmove(1,j,atrib)
            call filem(7,atrib)
            call schdl(8,0.1,atrib)
        endif
80     continue
        return
*****
9      if(nque.eq.1) return
*** similar to event 6
        nempty=0
        nlong=0
        do 90 j=7,nque+6
            if(nnq(j).eq.0) nempty=j
            if(nnq(j).ge.2) nlong=j
90     continue
        if(nlong.gt.0.and.nempty.gt.0) then
            call rmove(2,nlong,atrib)
            call filem(nempty,atrib)
            call schdl(9,0.01,atrib)
        endif
        return
*****
10     write(3,*)'error, event 10 called'
        return
*****
11     ATRIB(2)=GAMA(23.1,3.2,3)
        ATRIB(3)=1.0
        IF(TNOW.GT.(XX(1)-45.0))THEN
            IF(ATRIB(2).GT.70.0)ATRIB(2)=70
        ENDIF
        IF(ATRIB(2).GT.100.0)ATRIB(3)=2.0
        xx(2)=xx(8)*rlogn(15.0,4.0,1)
        RETURN

```

```

*****
12  write(3,*)tnow,'err, evl2'
    return
*****
13  ncount=ncount+1
    twait(ncount)=tnow-atrib(4)
    if(twait(ncount).gt.15.0) plus15=plus15+1
*** checkout time
    xrand=unfrm(0.0,1.0,3)
    if(xrand.lt.xx(40)) then
*** coupon time =(time/coupon x avg coupons/cust)/% cust using coupons
    ctime=xx(41)*xx(42)/xx(40)
    xx(43)=expon(ckout0,2)+expon(ctime,2)
    else
    ncoup=0
    xx(43)=expon(ckout0,2)
    endif
*** used to verify average checkout time
    ztot=ztot+xx(43)
    ckavg=((1-xx(4))*(ztot/ncount))+(xx(4)*xx(23))
    return
    end
*****
    subroutine sumout
    COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
1  ,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
    common/out1/ncash(1200),nobs,nexp,wtmax,maxckr,cash0,plus15
    common/out2/ckavg,ztot,ncount,twait(5000)
    dimension top(500)
    data ntop,top/0,500*0.0/
*** add time to process customers in store at closing
    endhrs=xx(6)*xx(5)/60.0
    totmin=0.0
    do 10 i=1,nobs
10  totmin=totmin+(ncash(i)*xx(7))
    tothrs=endhrs+totmin/60.0
*** calc avg and max waiting times
    write(3,*)' calc avg and max wait'
    xwait=0.0
    do 15 i=1,ncount
15  xwait=xwait+twait(i)
    avgwt=xwait/ncount
    swait=0.0
    do 20 i=1,ncount
20  swait=swait+(avgwt-twait(i))*2
    stdwt=(swait/ncount)**.5
    write(3,*)' average wait time=',avgwt,' std dev=',stdwt
*** reduce array to speed up sorting, don't count cust. in closed q
    top2=avgwt+(stdwt*1.0)
    top3=avgwt+(stdwt*5.0)
    write(3,*)' copy to top, waiting time>','top2,' and <','top3
    ntop=0

```

```

        do 25 i=1,ncount
            if(ntop.lt.500.and.twait(i).gt.top2.and.twait(i).lt.top3)then
                ntop=ntop+1
                top(ntop)=twait(i)
            endif
25      continue
*** sort to find top 1%
        icode=1
        write(*,*)'sorting'
35      if(icode.eq.1) then
            icode=0
            do 40 i=2,ntop
                if(top(i).gt.top(i-1)) then
                    temp=top(i-1)
                    top(i-1)=top(i)
                    top(i)=temp
                    icode=1
                endif
40      continue
            go to 35
        endif
        write(3,*)' after sorting',(top(i),i=1,15)
*** calc mean of top 1%
        n1=.01*real(ncount)
        totmax=0.0
        do 50 i=1,n1
50      totmax=totmax+top(i)
        wtmax=totmax/n1
        w99=top(n1)
        write(3,*)' n99=',w99,' top1%=',wtmax
*** balking
        nbalk=nncnt(90)+nncnt(91)+nncnt(92)+nncnt(93)
        write(3,*)' balks, line',nncnt(91),nncnt(92)
        write(3,*)'          parking',nncnt(90),' carts',nncnt(93)
        pbalk=real(nbalk)/real(nncnt(1))
        plus15=plus15/ncount
        write(4,100)int(xx(12)),int(xx(19)),int(xx(20)),int(xx(14)),nexp
1,nncnt(1),ckavg,int(xx(3)),pbalk,maxckr,tothrs,cash0,w99,avgwt
1,stdwt,plus15
100  format(2x,i2,2x,i2,2(1x,i3),2(1x,i4),1x,f4.2,1x,i2,2x,f4.3,1x,i2
1,1x,f6.1,1x,f4.2,3(1x,f5.2),1x,f3.2)
        nrpt=30/xx(7)
        write(3,200)(ncash(i),i=1,nobs,nrpt)
200  format(24(i3))
*** reset counters for subsequent runs
        nobs=0
        ncount=0
        ztot=0.0
        do 55 i=1,500
55      top(i)=0.0
        return
    end

```

APPENDIX B. INPUTS AND OUTPUTS

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**INPUT LEVELS FOR ANOVA AND EXPERIMENTAL DESIGN
LACKLAND AFB COMMISSARY**

```

GEN,FRITZ,COMM,10/01/89,9,,N,,N,N,72;ilist,iecho,ixqt,ipirh,ismry
LIMITS,41,4,700;
INIT,0.0,605.0; minutes opens
INTLC,XX(3)=8.0,XX(12)=1;
INTLC,XX(5)=3.04; service time
INTLC,XX(14)=0; arrival adjustment (% above or below input level)
INTLC,XX(20)=21; # of queues
; xx(5) = 2.71, 3.04, 3.27; values in ANOVA and regression
; xx(14) = -20, 0, 20; values in ANOVA and regression
; xx(14) = -30, -10, 10; values in regression
; xx(20) = 21, 1; values in ANOVA and regression
INTLC,XX(4)=.1,XX(7)=3,XX(9)=175,XX(10)=200,XX(11)=225;
INTLC,XX(17)=900,XX(18)=1900,XX(19)=21,XX(22)=23.0;
INTLC,XX(25)=1.0,XX(26)=2.00,XX(27)=3.92,XX(28)=4.68,XX(29)=5.75;
INTLC,XX(30)=5.67,XX(31)=5.57,XX(32)=5.63,XX(33)=5.10,XX(34)=5.25;
INTLC,XX(35)=2.15,XX(36)=0.00,XX(37)=0.00;
INTLC,XX(40)=0.60,XX(41)=0.167,XX(42)=3.26;
; extra low cashier hours
; INTLC,XX(50)=1.0,XX(51)=3,XX(52)=7,XX(53)=7,XX(54)=9,XX(55)=9;
; INTLC,XX(56)=10,XX(57)=11,XX(58)=11,XX(59)=12,XX(60)=13,XX(61)=13;
; INTLC,XX(62)=13,XX(63)=14,XX(64)=14,XX(65)=14,XX(66)=14,XX(67)=14;
; INTLC,XX(68)=14,XX(69)=14,XX(70)=8,XX(71)=0;
; low cashier hours
; INTLC,XX(50)=1.0,XX(51)=3,XX(52)=7,XX(53)=7,XX(54)=11,XX(55)=13;
; INTLC,XX(56)=15,XX(57)=15,XX(58)=16,XX(59)=16,XX(60)=16,XX(61)=17;
; INTLC,XX(62)=17,XX(63)=17,XX(64)=17,XX(65)=17,XX(66)=17,XX(67)=17;
; INTLC,XX(68)=17,XX(69)=17,XX(70)=14,XX(71)=0;
; medium cashier hours
INTLC,XX(50)=1.0,XX(51)=3,XX(52)=7,XX(53)=8,XX(54)=12,XX(55)=14;
INTLC,XX(56)=16,XX(57)=17,XX(58)=17,XX(59)=17,XX(60)=18,XX(61)=18;
INTLC,XX(62)=18,XX(63)=18,XX(64)=18,XX(65)=18,XX(66)=18,XX(67)=18;
INTLC,XX(68)=18,XX(69)=18,XX(70)=15,XX(71)=0;
; high cashier hours
; INTLC,XX(50)=1.0,XX(51)=3,XX(52)=7,XX(53)=9,XX(54)=13,XX(55)=15;
; INTLC,XX(56)=17,XX(57)=18,XX(58)=18,XX(59)=19,XX(60)=19,XX(61)=19;
; INTLC,XX(62)=19,XX(63)=19,XX(64)=19,XX(65)=19,XX(66)=19,XX(67)=20;
; INTLC,XX(68)=20,XX(69)=19,XX(70)=15,XX(71)=0;
; extra high cashier hours
; INTLC,XX(50)=0.0,XX(51)=4,XX(52)=8,XX(53)=10,XX(54)=17,XX(55)=19;
; INTLC,XX(56)=21,XX(57)=21,XX(58)=21,XX(59)=21,XX(60)=21,XX(61)=21;
; INTLC,XX(62)=21,XX(63)=21,XX(64)=21,XX(65)=21,XX(66)=21,XX(67)=21;
; INTLC,XX(68)=21,XX(69)=21,XX(70)=18,XX(71)=0;
SEEDS,4382381(1)/NO,8532327(2)/NO,1952779(3);

```

INPUT LEVELS FOR ANOVA AND EXPERIMENTAL DESIGN **RHEIN MAIN AB COMMISSARY**

```

GEN,FRITZ,COMM,10/01/89,8,,N,,N,N,72;ilist,iecho,ixqt,ipirh,ismry
LIMITS,41,4,700;
INIT,0.0,635.0; minutes opens
INTLC,XX(3)=8.0,XX(12)=1;
INTLC,XX(4)=.1,XX(7)=3,XX(9)=125,XX(10)=150,XX(11)=175;
INTLC,XX(5)=2.02; service time
INTLC,XX(14)=0; arrival adjustment (% above or below input level)
INTLC,XX(20)=10; # of queues
; xx(5) = 1.75, 2.02, 2.27; values in ANOVA and regression
; xx(14) = -25, 0, 25; values in ANOVA and regression
; xx(14) = -12, 12, 45; values in regression
; xx(20) = 10, 1; values in ANOVA and regression
INTLC,XX(17)=900,XX(18)=1930,XX(19)=10,XX(22)=15.0;
INTLC,XX(25)=1.0,XX(26)=1.35,XX(27)=2.13,XX(28)=2.23,XX(29)=2.48;
INTLC,XX(30)=2.58,XX(31)=2.75,XX(32)=4.03,XX(33)=4.58,XX(34)=3.85;
INTLC,XX(35)=2.55,XX(36)=1.57,XX(37)=0.00;
INTLC,XX(40)=.30,XX(41)=.167,XX(42)=.796;
; extra low hours
; INTLC,XX(50)=1.0,XX(51)=2,XX(52)=3,XX(53)=4,XX(54)=4,XX(55)=4;
; INTLC,XX(56)=4,XX(57)=5,XX(58)=5,XX(59)=5,XX(60)=5,XX(61)=5;
; INTLC,XX(62)=6,XX(63)=6,XX(64)=6,XX(65)=7,XX(66)=7,XX(67)=7;
; INTLC,XX(68)=7,XX(69)=7,XX(70)=7,XX(71)=6;
; low hours
; INTLC,XX(50)=1.0,XX(51)=3,XX(52)=4,XX(53)=5,XX(54)=5,XX(55)=5;
; INTLC,XX(56)=5,XX(57)=5,XX(58)=6,XX(59)=6,XX(60)=6,XX(61)=6;
; INTLC,XX(62)=7,XX(63)=7,XX(64)=8,XX(65)=9,XX(66)=9,XX(67)=9;
; INTLC,XX(68)=9,XX(69)=9,XX(70)=9,XX(71)=7;
; medium hours
INTLC,XX(50)=1.0,XX(51)=3,XX(52)=4,XX(53)=5,XX(54)=5,XX(55)=5;
INTLC,XX(56)=5,XX(57)=6,XX(58)=6,XX(59)=6,XX(60)=6,XX(61)=7;
INTLC,XX(62)=7,XX(63)=7,XX(64)=9,XX(65)=10,XX(66)=10,XX(67)=10;
INTLC,XX(68)=10,XX(69)=10,XX(70)=10,XX(71)=7;
; high hours
; INTLC,XX(50)=1.0,XX(51)=3,XX(52)=4,XX(53)=5,XX(54)=5,XX(55)=6;
; INTLC,XX(56)=6,XX(57)=7,XX(58)=7,XX(59)=7,XX(60)=7,XX(61)=8;
; INTLC,XX(62)=8,XX(63)=9,XX(64)=10,XX(65)=10,XX(66)=10,XX(67)=10;
; INTLC,XX(68)=10,XX(69)=10,XX(70)=10,XX(71)=7;
; high hours
; INTLC,XX(50)=1.0,XX(51)=3,XX(52)=4,XX(53)=5,XX(54)=6,XX(55)=6;
; INTLC,XX(56)=7,XX(57)=8,XX(58)=8,XX(59)=9,XX(60)=9,XX(61)=10;
; INTLC,XX(62)=10,XX(63)=10,XX(64)=10,XX(65)=10,XX(66)=10,XX(67)=10;
; INTLC,XX(68)=10,XX(69)=10,XX(70)=10,XX(71)=7;
SEEDS,4382381(1)/NO,8532327(2)/NO,1952779(3);

```

OUTPUT FROM LACKLAND AFB COMMISSARY

day	max ckr	max qs	arvl	#exp	#gen	ck out	add ckr	% balk	ckr use	total hrs	util rate	max wait	avg wait	std wait	+15
1	21	1	-30	1915	1964	3.45	5	.000	17	147.9	.82	9.44	1.63	2.72	.00
1	21	1	-30	1915	1928	3.37	5	.000	17	148.4	.76	7.23	.82	1.81	.00
1	21	1	-30	1915	1964	3.47	5	.000	16	137.9	.89	20.23	4.05	4.77	.03
1	21	1	-30	1915	1928	3.32	5	.000	16	138.3	.82	9.68	1.25	2.08	.00
1	21	1	-30	1915	1964	2.76	5	.000	14	117.9	.83	18.97	3.95	5.57	.08
1	21	1	-30	1915	1928	2.73	5	.000	14	118.1	.79	8.01	1.26	2.05	.00
1	21	1	-20	2191	2200	3.36	5	.000	17	148.6	.90	16.05	5.38	4.68	.04
1	21	1	-20	2191	2223	3.32	5	.000	17	148.9	.89	22.13	3.01	4.78	.05
1	21	1	-20	2191	2200	3.32	5	.000	16	138.4	.96	27.91	15.01	7.52	.57
1	21	1	-20	2191	2318	3.31	5	.000	16	138.9	1.00	33.84	22.38	6.85	.92
1	21	1	-20	2191	2219	2.75	5	.000	14	118.3	.94	28.21	12.74	9.37	.42
1	21	1	-20	2191	2268	2.67	5	.000	14	118.2	.93	23.12	10.53	8.18	.37
1	21	1	-10	2464	2488	3.04	5	.000	19	158.2	.85	8.96	1.07	1.78	.00
1	21	1	-10	2464	2573	2.95	5	.000	19	158.3	.86	7.30	1.69	2.20	.00
1	21	1	0	2740	2835	2.94	5	.000	19	159.1	.94	11.77	4.45	3.44	.00
1	21	1	0	2740	2661	2.91	5	.000	19	158.9	.86	10.00	2.99	2.86	.00
1	21	1	0	2740	2802	3.02	5	.000	18	158.6	.93	12.83	5.32	3.64	.00
1	21	1	0	2740	2795	3.00	5	.000	18	159.1	.93	11.41	6.00	3.56	.00
1	21	1	0	2740	2802	2.74	5	.000	18	158.2	.84	6.84	1.14	1.66	.00
1	21	1	0	2740	2795	2.68	5	.000	18	159.1	.83	7.67	1.04	1.70	.00
1	21	1	0	2740	2802	3.38	5	.000	20	170.5	.97	23.33	12.23	5.44	.31
1	21	1	0	2740	2795	3.27	5	.000	20	171.3	.94	15.30	9.48	4.03	.02
1	21	1	10	3012	3052	2.96	5	.000	18	160.5	1.00	26.82	19.12	4.64	.89
1	21	1	10	3012	3037	3.05	5	.024	18	160.5	1.00	38.76	18.83	9.73	.55
1	21	1	10	3012	2958	2.63	5	.000	18	159.1	.88	5.77	.98	1.53	.00
1	21	1	10	3012	3036	2.77	5	.000	18	158.9	.94	14.45	5.86	4.16	.00
1	21	1	10	3012	2995	3.33	5	.011	20	174.3	1.00	38.04	23.56	7.35	.85
1	21	1	10	3012	3102	3.35	5	.040	20	175.7	1.00	41.95	19.42	12.97	.47
1	21	1	20	3289	3419	2.98	5	.044	20	172.5	1.00	36.04	20.99	9.29	.71
1	21	1	20	3289	3192	3.04	5	.000	20	171.6	1.00	30.64	17.18	6.44	.61
1	21	1	20	3289	3390	2.67	5	.000	20	170.9	.93	12.74	5.71	3.27	.00
1	21	1	20	3289	3257	2.72	5	.000	20	171.2	.92	10.42	3.50	2.81	.00
1	21	1	20	3289	3323	3.28	5	.001	21	192.9	.99	29.60	14.82	9.57	.48
1	21	1	20	3289	3254	3.38	5	.000	21	195.1	.99	31.13	14.22	9.01	.44
1	21	21	-30	1915	1889	3.41	5	.000	17	144.2	.77	15.24	3.25	3.53	.01
1	21	21	-30	1915	1950	3.36	5	.000	17	147.7	.78	16.34	3.53	3.74	.02
1	21	21	-30	1915	1889	3.53	5	.000	16	134.2	.85	19.92	4.35	4.47	.03
1	21	21	-30	1915	1950	3.39	5	.000	16	137.8	.86	18.53	4.38	4.39	.03
1	21	21	-30	1915	1889	2.85	5	.000	14	114.2	.82	17.70	4.05	4.12	.02
1	21	21	-30	1915	1950	2.72	5	.000	14	117.4	.81	18.66	3.96	4.14	.02
1	21	21	-20	2191	2337	3.32	5	.000	17	148.8	.93	20.32	6.07	4.78	.05
1	21	21	-20	2191	2154	3.41	5	.000	17	149.1	.87	21.19	5.48	5.02	.05
1	21	21	-20	2191	2337	3.28	5	.000	16	139.0	.99	45.85	20.34	9.05	.71
1	21	21	-20	2191	2154	3.45	5	.000	16	139.1	.95	46.96	19.28	10.64	.64
1	21	21	-20	2191	2308	2.66	5	.010	14	118.8	.94	42.83	16.40	10.01	.58
1	21	21	-20	2191	2152	2.77	5	.000	14	118.0	.92	37.72	11.95	9.50	.34
1	21	21	-10	2464	2460	3.11	5	.000	19	155.4	.85	16.44	3.55	3.72	.01
1	21	21	-10	2464	2495	3.11	5	.000	19	158.3	.85	14.61	3.21	3.25	.01

1	21	21	0	2740	2757	3.08	5	.000	18	155.8	.95	21.63	6.01	5.01	.06
1	21	21	0	2740	2764	3.11	5	.000	18	158.1	.95	21.98	6.12	4.84	.05
1	21	21	0	2740	2757	2.74	5	.000	18	155.6	.83	11.63	2.75	2.84	.00
1	21	21	0	2740	2764	2.73	5	.000	18	157.9	.83	12.34	2.71	2.88	.01
1	21	21	0	2740	2757	3.41	5	.000	20	166.8	.97	31.04	10.05	6.53	.20
1	21	21	0	2740	2764	3.44	5	.000	20	170.1	.97	32.97	12.50	7.39	.34
1	21	21	0	2740	2653	3.02	5	.000	19	158.7	.89	20.65	5.14	4.94	.05
1	21	21	0	2740	2893	3.06	5	.000	19	158.9	.98	35.06	15.01	7.13	.47
1	21	21	10	3012	2965	3.11	5	.004	18	162.5	1.00	43.61	18.81	10.23	.60
1	21	21	10	3012	3080	2.99	5	.027	18	160.2	1.00	51.58	22.90	11.25	.74
1	21	21	10	3012	2965	2.76	5	.000	18	158.5	.91	20.00	5.04	4.56	.04
1	21	21	10	3012	3047	2.70	5	.000	18	158.8	.93	25.92	7.67	6.13	.12
1	21	21	10	3012	2963	3.45	5	.024	20	174.8	1.00	55.10	25.47	11.66	.81
1	21	21	10	3012	3094	3.29	5	.039	20	173.2	1.00	57.59	24.06	11.92	.76
1	21	21	20	3289	3258	3.03	5	.003	20	168.9	1.00	43.47	16.72	9.87	.52
1	21	21	20	3289	3264	3.09	5	.029	20	173.2	1.00	54.76	20.92	11.33	.68
1	21	21	20	3289	3254	2.78	5	.000	20	166.4	.93	18.39	4.52	4.11	.03
1	21	21	20	3289	3267	2.75	5	.000	20	169.4	.94	21.73	7.10	4.92	.07
1	21	21	20	3289	3254	3.38	5	.000	21	190.0	.98	33.06	11.94	8.13	.34
1	21	21	20	3289	3286	3.47	5	.019	21	196.3	1.00	54.98	19.97	13.19	.59

OUTPUT FROM RHEIN MAIN AB COMMISSARY

day	ckr	max qs	max arvl	#exp	#gen	ck out	add ckr	% balk	ckr use	total hrs	util rate	max wait	avg wait	std wait	+15
1	10	1	-25	1349	1288	1.81	8	.000	8	58.6	.76	7.19	1.01	1.79	.00
1	10	1	-25	1349	1285	1.80	8	.000	8	58.7	.77	14.46	2.33	3.73	.00
1	10	1	-25	1349	1370	2.04	8	.009	8	59.0	.94	24.97	15.01	6.37	.61
1	10	1	-25	1349	1320	2.09	8	.009	8	59.1	.93	22.97	11.74	5.39	.24
1	10	1	-25	1349	1303	2.36	8	.049	7	59.0	1.00	36.77	20.95	7.26	.76
1	10	1	-25	1349	1386	2.25	8	.087	7	57.5	1.00	42.38	24.67	7.38	.92
1	10	1	-12	1583	1471	1.85	8	.000	7	56.7	.95	13.10	4.83	4.10	.00
1	10	1	-12	1583	1564	1.85	8	.042	7	57.2	.96	27.87	12.84	8.68	.48
1	10	1	-12	1583	1471	2.12	8	.000	9	70.0	.84	7.23	1.38	1.85	.00
1	10	1	-12	1583	1531	2.07	8	.000	9	70.2	.87	18.51	4.55	4.61	.03
1	10	1	-12	1583	1566	1.85	8	.000	9	70.3	.78	7.76	1.55	2.18	.00
1	10	1	-12	1583	1602	1.71	8	.000	9	70.2	.74	5.04	.73	1.24	.00
1	10	1	0	1799	1742	2.15	8	.000	10	74.7	.94	16.27	4.83	4.83	.04
1	10	1	0	1799	1726	1.96	8	.000	10	75.2	.85	14.21	5.72	5.05	.00
1	10	1	0	1799	1742	2.37	8	.015	10	75.3	1.00	30.57	15.49	6.68	.52
1	10	1	0	1799	1737	2.23	8	.007	10	75.4	.98	24.68	13.47	8.13	.53
1	10	1	0	1799	1742	1.82	8	.000	9	69.8	.86	6.87	1.34	1.84	.00
1	10	1	0	1799	1726	1.72	8	.000	9	70.4	.81	8.96	2.78	2.96	.00
1	10	1	0	1799	1742	2.40	8	.000	10	80.5	.96	13.86	5.51	3.99	.00
1	10	1	0	1799	1726	2.23	8	.000	10	80.8	.89	21.00	6.71	6.72	.17
1	10	1	12	2016	1968	2.14	8	.081	9	72.8	.99	30.78	20.45	7.98	.84
1	10	1	12	2016	1979	1.99	8	.097	9	71.0	.97	35.90	18.85	9.59	.72
1	10	1	12	2016	2049	1.72	8	.015	9	70.4	.95	20.55	11.94	6.10	.39
1	10	1	12	2016	1949	1.77	8	.000	9	70.4	.93	17.80	5.71	4.05	.03
1	10	1	12	2016	2051	2.24	8	.037	10	83.8	1.00	33.18	18.26	6.37	.60
1	10	1	12	2016	2000	2.31	8	.042	10	83.1	1.00	28.30	20.60	4.68	.91
1	10	1	12	2016	2096	1.74	8	.001	10	75.1	.92	21.05	6.46	5.16	.08
1	10	1	12	2016	1962	1.79	8	.000	10	74.8	.89	7.61	2.94	2.06	.00
1	10	1	25	2252	2307	1.75	8	.033	10	75.2	.99	32.31	14.52	6.23	.44
1	10	1	25	2252	2152	1.78	8	.009	10	75.0	.97	20.35	10.79	6.04	.33
1	10	1	25	2252	2290	1.75	8	.078	9	71.2	1.00	30.02	17.48	6.06	.65
1	10	1	25	2252	2200	1.78	8	.082	9	70.8	.99	29.94	17.56	7.39	.66
1	10	1	25	2252	2051	2.08	8	.000	10	80.4	.98	22.73	10.04	5.87	.21
1	10	1	25	2252	2182	2.00	8	.024	10	81.1	.99	26.49	15.30	6.60	.59
1	10	1	25	2252	2116	2.07	8	.001	10	87.5	.89	22.90	7.53	7.01	.22
1	10	1	25	2252	2107	2.00	8	.000	10	87.2	.90	20.57	6.48	6.27	.13
1	10	1	45	2613	2578	1.76	8	.040	10	81.6	1.00	23.26	14.22	4.98	.42
1	10	1	45	2613	2403	1.72	8	.000	10	81.1	.96	17.78	5.24	4.67	.05
1	10	1	45	2613	2588	1.80	8	.026	10	87.9	.96	25.86	10.27	7.32	.26
1	10	1	45	2613	2498	1.72	8	.000	10	88.3	.90	16.34	5.89	5.55	.06
1	10	10	-25	1349	1361	1.75	8	.007	8	58.8	.81	35.50	5.34	7.22	.11
1	10	10	-25	1349	1298	1.74	8	.000	8	58.8	.75	13.03	2.38	2.90	.00
1	10	10	-25	1349	1352	2.03	8	.000	8	59.0	.92	24.31	8.12	5.91	.13
1	10	10	-25	1349	1358	2.10	8	.015	8	59.2	.93	42.34	13.62	10.12	.42
1	10	10	-25	1349	1308	2.31	8	.069	7	56.9	.99	48.51	19.81	12.66	.59
1	10	10	-25	1349	1360	2.30	8	.071	7	57.6	1.00	53.51	24.84	10.93	.81

1	10	10	-12	1583	1521	1.71	8	.000	7	57.1	.91	18.71	5.20	4.62	.04
1	10	10	-12	1583	1531	1.77	8	.039	7	56.7	.94	34.49	11.20	8.74	.32
1	10	10	-12	1583	1559	1.95	8	.000	9	70.3	.83	15.85	3.13	3.60	.01
1	10	10	-12	1583	1631	2.08	8	.000	9	70.4	.93	29.50	7.91	6.36	.12
1	10	10	-12	1583	1572	1.79	8	.000	9	70.3	.77	10.00	1.93	2.33	.00
1	10	10	-12	1583	1499	1.70	8	.000	9	70.4	.68	11.51	2.04	2.76	.01
1	10	10	0	1799	1804	2.03	8	.002	10	75.6	.91	22.36	5.54	5.40	.08
1	10	10	0	1799	1754	2.07	8	.002	10	75.7	.90	32.44	7.45	7.91	.16
1	10	10	0	1799	1806	2.25	8	.022	10	75.4	.99	42.94	13.30	9.44	.35
1	10	10	0	1799	1766	2.33	8	.025	10	75.8	.99	41.25	17.99	9.27	.61
1	10	10	0	1799	1769	1.78	8	.000	9	70.6	.85	14.42	2.97	3.47	.01
1	10	10	0	1799	1737	1.81	8	.000	9	70.5	.86	17.76	3.69	3.95	.02
1	10	10	0	1799	1769	2.26	8	.000	10	81.2	.92	25.15	5.30	5.79	.08
1	10	10	0	1799	1737	2.30	8	.000	10	81.1	.93	27.79	7.31	6.61	.13
1	10	10	12	2016	1898	1.72	8	.000	10	75.2	.82	16.87	3.02	4.06	.02
1	10	10	12	2016	1967	1.67	8	.000	10	75.1	.83	13.02	2.83	2.96	.00
1	10	10	12	2016	1928	2.24	8	.000	10	81.8	.99	29.30	10.93	6.70	.25
1	10	10	12	2016	2036	2.19	8	.013	10	83.0	.99	36.58	15.64	8.57	.52
1	10	10	12	2016	2007	2.04	8	.079	9	71.7	1.00	48.01	19.37	10.32	.64
1	10	10	12	2016	1966	2.10	8	.078	9	72.4	1.00	42.04	19.32	9.03	.69
1	10	10	12	2016	1891	1.74	8	.000	9	70.3	.89	20.61	4.33	4.34	.03
1	10	10	12	2016	1976	1.69	8	.000	9	70.7	.92	21.60	5.43	4.85	.05
1	10	10	25	2252	2141	1.71	8	.000	10	75.2	.93	19.26	5.43	4.59	.04
1	10	10	25	2252	2167	1.69	8	.000	10	75.1	.93	21.33	6.55	5.10	.07
1	10	10	25	2252	2180	1.70	8	.034	9	70.6	.98	34.07	14.51	8.05	.46
1	10	10	25	2252	2220	1.68	8	.020	9	71.7	.99	32.34	11.01	7.61	.26
1	10	10	25	2252	2242	2.06	8	.060	10	82.2	1.00	42.08	18.93	7.94	.68
1	10	10	25	2252	2199	2.06	8	.039	10	82.3	.99	37.00	15.08	8.30	.47
1	10	10	25	2252	2167	2.06	8	.000	10	89.0	.94	30.92	9.03	7.59	.22
1	10	10	25	2252	2218	2.04	8	.000	10	88.9	.94	27.61	8.51	7.29	.20
1	10	10	45	2613	2552	1.70	8	.024	10	81.5	.98	34.82	10.32	8.15	.25
1	10	10	45	2613	2568	1.75	8	.042	10	81.9	.99	40.70	14.93	9.18	.45
1	10	10	45	2613	2550	1.74	8	.020	10	88.2	.91	28.29	7.55	7.67	.21
1	10	10	45	2613	2588	1.77	8	.032	10	88.1	.94	31.97	9.84	7.83	.23

INPUT FOR INITIAL RUNS

```

GEN,FRITZ,COMM,10/01/89,9,,N,,N,N,72;ilist,iecho,ixqt,ipirh,ismry
LIMITS,41,4,700;
INIT,0.0,605.0; minutes opens
INTLC,XX(3)=8.0,XX(12)=1,XX(14)=0;
INTLC,XX(4)=.1,XX(5)=3.04,XX(7)=3,XX(9)=175,XX(10)=200,XX(11)=225;
INTLC,XX(17)=900,XX(18)=1900,XX(19)=21,XX(20)=21,XX(22)=23.0;
INTLC,XX(25)=1.0,XX(26)=2.00,XX(27)=3.92,XX(28)=4.68,XX(29)=5.75;
INTLC,XX(30)=5.67,XX(31)=5.57,XX(32)=5.63,XX(33)=5.10,XX(34)=5.25;
INTLC,XX(35)=2.15,XX(36)=0.00,XX(37)=0.00;
INTLC,XX(40)=0.60,XX(41)=0.167,XX(42)=3.26;
INTLC,XX(50)=1.0,XX(51)=3,XX(52)=7,XX(53)=8,XX(54)=12,XX(55)=14;
INTLC,XX(56)=16,XX(57)=17,XX(58)=17,XX(59)=17,XX(60)=18,XX(61)=18;
INTLC,XX(62)=18,XX(63)=18,XX(64)=18,XX(65)=18,XX(66)=18,XX(67)=18;
INTLC,XX(68)=18,XX(69)=18,XX(70)=15,XX(71)=0;
SEEDS,4382381(1)/NO,8532327(2)/NO,1952779(3);

```

OUTPUT FOR INITIAL RUNS

day	max ckr	max qs	max arvl	#exp	#gen	out	ckr	add	%	ckr	to	util	max	avg	std	
												rate	wait	wait	wait	+15
***	vary	cashiers,	maintain	average	waiting	time										
1	21	21	0	2740	2757	3.08	8	.000	22	154.3	.95	22.86	7.49	5.31	.10	
1	21	21	0	2740	2764	3.14	8	.000	22	155.1	.96	22.81	7.92	5.21	.10	
1	21	21	0	2740	2802	3.07	8	.000	22	153.3	.96	23.55	7.51	5.39	.10	
1	21	21	0	2740	2795	2.97	8	.000	22	149.1	.96	21.38	7.08	4.93	.08	
1	21	21	0	2740	2653	3.08	8	.000	22	148.7	.96	22.74	7.31	5.00	.08	
1	21	21	0	2740	2775	2.94	8	.000	22	147.4	.98	22.52	7.17	5.04	.08	
1	21	21	0	2740	2661	2.99	8	.000	22	144.3	.97	23.00	7.04	5.15	.08	
1	21	21	0	2740	2785	2.97	8	.000	22	149.3	.96	22.59	7.05	5.15	.08	
1	21	21	0	2740	2713	3.07	8	.000	20	147.1	.97	24.56	7.45	5.30	.09	
1	21	21	0	2740	2753	3.06	8	.000	20	149.7	.97	23.61	7.87	5.25	.10	
***	hold	cashiers	constant,	vary	wait	times										
1	21	21	0	2740	2757	3.08	8	.000	18	155.8	.95	21.63	6.01	5.01	.06	
1	21	21	0	2740	2764	3.14	8	.000	18	155.9	.96	25.57	9.02	5.87	.16	
1	21	21	0	2740	2802	3.04	8	.000	18	155.8	.95	26.84	7.67	6.11	.12	
1	21	21	0	2740	2795	2.95	8	.000	18	156.3	.92	25.12	8.21	5.99	.14	
1	21	21	0	2740	2653	3.11	8	.000	18	155.1	.93	20.05	5.39	4.72	.04	
1	21	21	0	2740	2775	3.01	8	.000	18	156.0	.95	23.37	6.48	5.07	.07	
1	21	21	0	2740	2661	2.96	8	.000	18	156.0	.89	20.32	5.48	4.83	.05	
1	21	21	0	2740	2785	3.02	8	.000	18	156.9	.94	21.08	6.37	4.98	.07	
1	21	21	0	2740	2643	3.08	8	.000	18	155.2	.90	17.03	3.83	3.77	.02	
1	21	21	0	2740	2716	3.02	8	.000	18	156.1	.91	21.68	5.85	5.07	.06	

APPENDIX C. STATISTICAL ANALYSIS

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ANALYSIS OF VARIANCE - INPUT FILE

TITLE 'ANALYSIS OF VARIANCE FOR THESIS RESEARCH';
 OPTIONS LINESIZE=78 PAGESIZE=60;

DATA WAIT;

INPUT store q \$ arvl \$ x2 x3 ckout \$ x5 chrs x7 max wait \$
 x8 x9 @;

CARDS;

1	a1	b3	2223	2223	c6	.000	148.9	.89	22.13	d1	4.78	.05
1	a1	b3	2200	2200	c6	.000	138.4	.96	27.91	d3	7.52	.57
1	a1	b3	2318	2318	c6	.000	138.9	1.00	33.84	d3	6.85	.92
1	a1	b3	2219	2219	c4	.000	118.3	.94	28.21	d2	9.37	.42
1	a1	b3	2268	2268	c4	.000	118.2	.93	23.12	d2	8.18	.37
1	a1	b5	2802	2802	c5	.000	158.6	.93	12.83	d2	3.64	.00
1	a1	b5	2795	2795	c5	.000	159.1	.93	11.41	d2	3.56	.00
1	a1	b5	2802	2802	c4	.000	158.2	.84	6.84	d1	1.66	.00
1	a1	b5	2795	2795	c4	.000	159.1	.83	7.67	d1	1.70	.00
1	a1	b5	2802	2802	c6	.000	170.5	.97	23.33	d2	5.44	.31
1	a1	b5	2795	2795	c6	.000	171.3	.94	15.30	d2	4.03	.02
1	a1	b5	2835	2835	c5	.000	159.1	.94	11.77	d1	3.44	.00
1	a1	b5	2661	2661	c5	.000	158.9	.86	10.00	d1	2.86	.00
1	a1	b6	3419	3269	c6	.044	172.5	1.00	36.04	d3	9.29	.71
1	a1	b6	3192	3192	c5	.000	171.6	1.00	30.64	d3	6.44	.61
1	a1	b6	3390	3390	c4	.000	170.9	.93	12.74	d2	3.27	.00
1	a1	b6	3257	3257	c4	.000	171.2	.92	10.42	d1	2.81	.00
1	a1	b6	3323	3320	c6	.001	192.9	.99	29.60	d2	9.57	.48
1	a1	b6	3254	3254	c6	.000	195.1	.99	31.13	d2	9.01	.44
1	a2	b3	2337	2337	c6	.000	148.8	.93	20.32	d2	4.78	.05
1	a2	b3	2154	2154	c6	.000	149.1	.87	21.19	d2	5.02	.05
1	a2	b3	2337	2337	c6	.000	139.0	.99	45.85	d3	9.05	.71
1	a2	b3	2154	2154	c6	.000	139.1	.95	46.96	d3	10.64	.64
1	a2	b3	2308	2285	c4	.010	118.8	.94	42.83	d3	10.01	.58
1	a2	b3	2152	2152	c4	.000	118.0	.92	37.72	d2	9.50	.34
1	a2	b5	2757	2757	c5	.000	155.8	.95	21.63	d2	5.01	.06
1	a2	b5	2764	2764	c5	.000	158.1	.95	21.98	d2	4.84	.05
1	a2	b5	2757	2757	c4	.000	155.6	.83	11.63	d1	2.84	.00
1	a2	b5	2764	2764	c4	.000	157.9	.83	12.34	d1	2.88	.01
1	a2	b5	2757	2757	c6	.000	166.8	.97	31.04	d2	6.53	.20
1	a2	b5	2764	2764	c6	.000	170.1	.97	32.97	d2	7.39	.34
1	a2	b5	2653	2653	c5	.000	158.7	.89	20.65	d2	4.94	.05
1	a2	b5	2893	2893	c5	.000	158.9	.98	35.06	d3	7.13	.47
1	a2	b6	3258	3248	c5	.003	168.9	1.00	43.47	d3	9.87	.52
1	a2	b6	3264	3169	c5	.029	173.2	1.00	54.76	d3	11.33	.68
1	a2	b6	3254	3254	c4	.000	166.4	.93	18.39	d1	4.11	.03
1	a2	b6	3267	3267	c4	.000	169.4	.94	21.73	d2	4.92	.07
1	a2	b6	3254	3254	c6	.000	190.0	.98	33.06	d2	8.13	.34
1	a2	b6	3286	3224	c6	.019	196.3	1.00	54.98	d3	13.19	.59
2	a1	b1	1288	1288	c1	.000	58.6	.76	7.19	d1	1.79	.00
2	a1	b1	1285	1285	c1	.000	58.7	.77	14.46	d1	3.73	.00
2	a1	b1	1370	1358	c2	.009	59.0	.94	24.97	d3	6.37	.61
2	a1	b1	1320	1308	c2	.009	59.1	.93	22.97	d2	5.39	.24

2	a1	b1	1303	1239	c2	.049	59.0	1.00	36.77	d3	7.26	.76
2	a1	b1	1386	1265	c3	.087	57.5	1.00	42.38	d3	7.38	.92
2	a1	b2	1742	1742	c3	.000	74.7	.94	16.27	d1	4.83	.04
2	a1	b2	1726	1426	c2	.000	75.2	.85	14.21	d2	5.05	.00
2	a1	b2	1742	1716	c3	.015	75.3	1.00	30.57	d3	6.68	.52
2	a1	b2	1737	1725	c3	.007	75.4	.98	24.68	d2	8.13	.53
2	a1	b2	1742	1742	c1	.000	69.8	.86	6.87	d1	1.84	.00
2	a1	b2	1726	1726	c1	.000	70.4	.81	8.96	d1	2.96	.00
2	a1	b2	1742	1742	c3	.000	80.5	.96	13.86	d2	3.99	.00
2	a1	b2	1726	1726	c3	.000	80.8	.89	21.00	d2	6.72	.17
2	a1	b4	2307	2231	c1	.033	75.2	.99	32.31	d2	6.23	.44
2	a1	b4	2152	2133	c1	.009	75.0	.97	20.35	d2	6.04	.33
2	a1	b4	2290	2111	c1	.078	71.2	1.00	30.02	d3	6.06	.65
2	a1	b4	2200	2020	c1	.082	70.8	.99	29.94	d3	7.39	.66
2	a1	b4	2051	2051	c2	.000	80.4	.98	22.73	d2	5.87	.21
2	a1	b4	2182	2130	c2	.024	81.1	.99	26.49	d3	6.60	.59
2	a1	b4	2116	2114	c2	.001	87.5	.89	22.90	d2	7.01	.22
2	a1	b4	2107	2107	c2	.000	87.2	.90	20.57	d2	6.27	.13
2	a2	b1	1361	1351	c1	.007	58.8	.81	35.50	d2	7.22	.11
2	a2	b1	1298	1298	c1	.000	58.8	.75	13.03	d1	2.90	.00
2	a2	b1	1352	1352	c2	.000	59.0	.92	24.31	d2	5.91	.13
2	a2	b1	1358	1338	c2	.015	59.2	.93	42.34	d2	10.12	.42
2	a2	b1	1308	1218	c3	.069	56.9	.99	48.51	d3	12.66	.59
2	a2	b1	1360	1263	c3	.071	57.6	1.00	53.51	d3	10.93	.81
2	a2	b2	1804	1800	c2	.002	75.6	.91	22.36	d2	5.40	.08
2	a2	b2	1754	1750	c2	.002	75.7	.90	32.44	d2	7.91	.16
2	a2	b2	1806	1766	c3	.022	75.4	.99	42.94	d2	9.44	.35
2	a2	b2	1766	1722	c3	.025	75.8	.99	41.25	d3	9.27	.61
2	a2	b2	1769	1769	c1	.000	70.6	.85	14.42	d1	3.47	.01
2	a2	b2	1737	1737	c1	.000	70.5	.86	17.76	d1	3.95	.02
2	a2	b2	1769	1769	c3	.000	81.2	.92	25.15	d2	5.79	.08
2	a2	b2	1737	1737	c3	.000	81.1	.93	27.79	d2	6.61	.13
2	a2	b4	2141	2141	c1	.000	75.2	.93	19.26	d2	4.59	.04
2	a2	b4	2167	2167	c1	.000	75.1	.93	21.33	d2	5.10	.07
2	a2	b4	2180	2106	c1	.034	70.6	.98	34.07	d2	8.05	.46
2	a2	b4	2220	2176	c1	.020	71.7	.99	32.34	d2	7.61	.26
2	a2	b4	2242	2107	c2	.060	82.2	1.00	42.08	d3	7.94	.68
2	a2	b4	2199	2113	c2	.039	82.3	.99	37.00	d3	8.30	.47
2	a2	b4	2167	2167	c2	.000	89.0	.94	30.92	d2	7.59	.22
2	a2	b4	2218	2218	c2	.000	88.9	.94	27.61	d2	7.29	.20

```

;
proc glm;
  class q arvl ckout wait;
  model chrs = q | arvl | ckout | wait @2;
run;

```

ANALYSIS OF VARIANCE - OUTPUT

General Linear Models Procedure Class Level Information

Class	Levels	Values
Q	2	a1 a2
ARVL	6	b1 b2 b3 b4 b5 b6
CKOUT	6	c1 c2 c3 c4 c5 c6
WAIT	3	d1 d2 d3

Number of observations in data set = 83

General Linear Models Procedure

Dependent Variable: CHRS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	40	173697.2584	4342.4315	490.80	0.0001
Error	42	371.6026	8.8477		
C Total	82	174068.8610			

R-Square	C.V.	Root MSE	CHRS Mean
0.997865	2.636466	2.974505	112.821687

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Q	1	6.4736	6.4736	0.73	0.3972
ARVL	5	169506.8702	33901.3740	3831.67	0.0001
Q*ARVL	5	45.8905	9.1781	1.04	0.4085
CKOUT	4	3289.0190	822.2548	92.93	0.0001
Q*CKOUT	4	24.7244	6.1811	0.70	0.5972
ARVL*CKOUT	6	442.5665	73.7611	8.34	0.0001
WAIT	2	179.5511	89.7756	10.15	0.0003
Q*WAIT	2	22.5149	11.2575	1.27	0.2907
ARVL*WAIT	9	122.2100	13.5789	1.53	0.1675
CKOUT*WAIT	2	57.4381	28.7190	3.25	0.0489

REGRESSION ANALYSIS - INPUT FILE

TITLE 'REGRESSION ANALYSIS OF THESIS RESEARCH A: THSREG.SAS';
 OPTIONS LINESIZE=78 PAGESIZE=60;

DATA WAIT;

INPUT store q d1 d2 cust ckout balk chrs util max wait d8 plus15 @;

qxcust = q * cust;
 qxck = q * ckout;
 qxwait = q * wait;
 qxchrs = q * chrs;
 custxck = cust * ckout;
 custlgck= cust * log(ckout;
 custxwt = cust * wait;
 ckxwait = ckout * wait;
 custxhr = cust * chrs;
 ckxchrs = ckout * chrs;
 hrxwait = chrs * wait;

CARDS;

1	1	-30	1964	1964	3.45	.000	147.9	.82	9.44	1.63	2.72	.00
1	1	-30	1928	1928	3.37	.000	148.4	.76	7.23	.82	1.81	.00
1	1	-30	1964	1964	3.47	.000	137.9	.89	20.23	4.05	4.77	.03
1	1	-30	1928	1928	3.32	.000	138.3	.82	9.68	1.25	2.08	.00
1	1	-30	1964	1964	2.76	.000	117.9	.83	18.97	3.95	5.57	.08
1	1	-30	1928	1928	2.73	.000	118.1	.79	8.01	1.26	2.05	.00
1	1	-20	2200	2200	3.36	.000	148.6	.90	16.05	5.38	4.68	.04
1	1	-20	2223	2223	3.32	.000	148.9	.89	22.13	3.01	4.78	.05
1	1	-20	2200	2200	3.32	.000	138.4	.96	27.91	15.01	7.52	.57
1	1	-20	2318	2318	3.31	.000	138.9	1.00	33.84	22.38	6.85	.92
1	1	-20	2219	2219	2.75	.000	118.3	.94	28.21	12.74	9.37	.42
1	1	-20	2268	2268	2.67	.000	118.2	.93	23.12	10.53	8.18	.37
1	1	-10	2488	2488	3.04	.000	158.2	.85	8.96	1.07	1.78	.00
1	1	-10	2573	2573	2.95	.000	158.3	.86	7.30	1.69	2.20	.00
1	1	0	2802	2802	3.02	.000	158.6	.93	12.83	5.32	3.64	.00
1	1	0	2795	2795	3.00	.000	159.1	.93	11.41	6.00	3.56	.00
1	1	0	2802	2802	2.74	.000	158.2	.84	6.84	1.14	1.66	.00
1	1	0	2795	2795	2.68	.000	159.1	.83	7.67	1.04	1.70	.00
1	1	0	2802	2802	3.38	.000	170.5	.97	23.33	12.23	5.44	.31
1	1	0	2795	2795	3.27	.000	171.3	.94	15.30	9.48	4.03	.02
1	1	0	2835	2835	2.94	.000	159.1	.94	11.77	4.45	3.44	.00
1	1	0	2661	2661	2.91	.000	158.9	.86	10.00	2.99	2.86	.00
1	1	10	3052	3052	2.96	.000	160.5	1.00	26.82	19.12	4.64	.89
1	1	10	3037	2964	3.05	.024	160.5	1.00	38.76	18.83	9.73	.55
1	1	10	2958	2958	2.63	.000	159.1	.88	5.77	.98	1.53	.00
1	1	10	3036	3036	2.77	.000	158.9	.94	14.45	5.86	4.16	.00
1	1	10	2995	2962	3.33	.011	174.3	1.00	38.04	23.56	7.35	.85
1	1	10	3102	2977	3.35	.040	175.7	1.00	41.95	19.42	12.97	.47
1	1	20	3419	3269	2.98	.044	172.5	1.00	36.04	20.99	9.29	.71
1	1	20	3192	3192	3.04	.000	171.6	1.00	30.64	17.18	6.44	.61
1	1	20	3390	3390	2.67	.000	170.9	.93	12.74	5.71	3.27	.00

1	1	20	3257	3257	2.72	.000	171.2	.92	10.42	3.50	2.81	.00
1	1	20	3323	3320	3.28	.001	192.9	.99	29.60	14.82	9.57	.48
1	1	20	3254	3254	3.38	.000	195.1	.99	31.13	14.22	9.01	.44
1	2	-30	1889	1889	3.41	.000	144.2	.77	15.24	3.25	3.53	.01
1	2	-30	1950	1950	3.36	.000	147.7	.78	16.34	3.53	3.74	.02
1	2	-30	1889	1889	3.53	.000	134.2	.85	19.92	4.35	4.47	.03
1	2	-30	1950	1950	3.39	.000	137.8	.86	18.53	4.38	4.39	.03
1	2	-30	1889	1889	2.85	.000	114.2	.82	17.70	4.05	4.12	.02
1	2	-30	1950	1950	2.72	.000	117.4	.81	18.66	3.96	4.14	.02
1	2	-20	2337	2337	3.32	.000	148.8	.93	20.32	6.07	4.78	.05
1	2	-20	2154	2154	3.41	.000	149.1	.87	21.19	5.48	5.02	.05
1	2	-20	2337	2337	3.28	.000	139.0	.99	45.85	20.34	9.05	.71
1	2	-20	2154	2154	3.45	.000	139.1	.95	46.96	19.28	10.64	.64
1	2	-20	2308	2285	2.66	.010	118.8	.94	42.83	16.40	10.01	.58
1	2	-20	2152	2152	2.77	.000	118.0	.92	37.72	11.95	9.50	.34
1	2	-10	2460	2460	3.11	.000	155.4	.85	16.44	3.55	3.72	.01
1	2	-10	2495	2495	3.11	.000	158.3	.85	14.61	3.21	3.25	.01
1	2	0	2757	2757	3.08	.000	155.8	.95	21.63	6.01	5.01	.06
1	2	0	2764	2764	3.11	.000	158.1	.95	21.98	6.12	4.84	.05
1	2	0	2757	2757	2.74	.000	155.6	.83	11.63	2.75	2.84	.00
1	2	0	2764	2764	2.73	.000	157.9	.83	12.34	2.71	2.88	.01
1	2	0	2757	2757	3.41	.000	166.8	.97	31.04	10.05	6.53	.20
1	2	0	2764	2764	3.44	.000	170.1	.97	32.97	12.50	7.39	.34
1	2	0	2653	2653	3.02	.000	158.7	.89	20.65	5.14	4.94	.05
1	2	0	2893	2893	3.06	.000	158.9	.98	35.06	15.01	7.13	.47
1	2	10	2965	2953	3.11	.004	162.5	1.00	43.61	18.81	10.23	.60
1	2	10	3080	2997	2.99	.027	160.2	1.00	51.58	22.90	11.25	.74
1	2	10	2965	2965	2.76	.000	158.5	.91	20.00	5.04	4.56	.04
1	2	10	3047	3047	2.70	.000	158.8	.93	25.92	7.67	6.13	.12
1	2	10	2963	2892	3.45	.024	174.8	1.00	55.10	25.47	11.66	.81
1	2	10	3094	2973	3.29	.039	173.2	1.00	57.59	24.06	11.92	.76
1	2	20	3258	3248	3.03	.003	168.9	1.00	43.47	16.72	9.87	.52
1	2	20	3264	3169	3.09	.029	173.2	1.00	54.76	20.92	11.33	.68
1	2	20	3254	3254	2.78	.000	166.4	.93	18.39	4.52	4.11	.03
1	2	20	3267	3267	2.75	.000	169.4	.94	21.73	7.10	4.92	.07
1	2	20	3254	3254	3.38	.000	190.0	.98	33.06	11.94	8.13	.34
1	2	20	3286	3224	3.47	.019	196.3	1.00	54.98	19.97	13.19	.59
2	1	-25	1288	1288	1.81	.000	58.6	.76	7.19	1.01	1.79	.00
2	1	-25	1285	1285	1.80	.000	58.7	.77	14.46	2.33	3.73	.00
2	1	-25	1370	1358	2.04	.009	59.0	.94	24.97	15.01	6.37	.61
2	1	-25	1320	1308	2.09	.009	59.1	.93	22.97	11.74	5.39	.24
2	1	-25	1303	1239	2.36	.049	59.0	1.00	36.77	20.95	7.26	.76
2	1	-25	1386	1265	2.25	.087	57.5	1.00	42.38	24.67	7.38	.92
2	1	-12	1471	1471	1.85	.000	56.7	.95	13.10	4.83	4.10	.00
2	1	-12	1564	1498	1.85	.042	57.2	.96	27.87	12.84	8.68	.48
2	1	-12	1471	1471	2.12	.000	70.0	.84	7.23	1.38	1.85	.00
2	1	-12	1531	1531	2.07	.000	70.2	.87	18.51	4.55	4.61	.03
2	1	-12	1566	1566	1.85	.000	70.3	.78	7.76	1.55	2.18	.00
2	1	-12	1602	1602	1.71	.000	70.2	.74	5.04	.73	1.24	.00
2	1	0	1742	1742	2.15	.000	74.7	.94	16.27	4.83	4.83	.04
2	1	0	1726	1426	1.96	.000	75.2	.85	14.21	5.72	5.05	.00
2	1	0	1742	1716	2.37	.015	75.3	1.00	30.57	15.49	6.68	.52

2	1	0	1737	1725	2.23	.007	75.4	.98	24.68	13.47	8.13	.53
2	1	0	1742	1742	1.82	.000	69.8	.86	6.87	1.34	1.84	.00
2	1	0	1726	1726	1.72	.000	70.4	.81	8.96	2.78	2.96	.00
2	1	0	1742	1742	2.40	.000	80.5	.96	13.86	5.51	3.99	.00
2	1	0	1726	1726	2.23	.000	80.8	.89	21.00	6.71	6.72	.17
2	1	12	1968	1809	2.14	.081	72.8	.99	30.78	20.45	7.98	.84
2	1	12	1979	1787	1.99	.097	71.0	.97	35.90	18.85	9.59	.72
2	1	12	2049	2018	1.72	.015	70.4	.95	20.55	11.94	6.10	.39
2	1	12	1949	1949	1.77	.000	70.4	.93	17.80	5.71	4.05	.03
2	1	12	2051	1957	2.24	.037	83.8	1.00	33.18	18.26	6.37	.60
2	1	12	2000	1916	2.31	.042	83.1	1.00	28.30	20.60	4.68	.91
2	1	12	2096	2094	1.74	.001	75.1	.92	21.05	6.46	5.16	.08
2	1	12	1962	1962	1.79	.000	74.8	.89	7.61	2.94	2.06	.00
2	1	25	2307	2231	1.75	.033	75.2	.99	32.31	14.52	6.23	.44
2	1	25	2152	2133	1.78	.009	75.0	.97	20.35	10.79	6.04	.33
2	1	25	2290	2111	1.75	.078	71.2	1.00	30.02	17.48	6.06	.65
2	1	25	2200	2020	1.78	.082	70.8	.99	29.94	17.56	7.39	.66
2	1	25	2051	2051	2.08	.000	80.4	.98	22.73	10.04	5.87	.21
2	1	25	2182	2130	2.00	.024	81.1	.99	26.49	15.30	6.60	.59
2	1	25	2116	2114	2.07	.001	87.5	.89	22.90	7.53	7.01	.22
2	1	25	2107	2107	2.00	.000	87.2	.90	20.57	6.48	6.27	.13
2	1	45	2578	2475	1.76	.040	81.6	1.00	23.26	14.22	4.98	.42
2	1	45	2403	2403	1.72	.000	81.1	.96	17.78	5.24	4.67	.05
2	1	45	2588	2521	1.80	.026	87.9	.96	25.86	10.27	7.32	.26
2	1	45	2498	2498	1.72	.000	88.3	.90	16.34	5.89	5.55	.06
2	2	-25	1361	1351	1.75	.007	58.8	.81	35.50	5.34	7.22	.11
2	2	-25	1298	1298	1.74	.000	58.8	.75	13.03	2.38	2.90	.00
2	2	-25	1352	1352	2.03	.000	59.0	.92	24.31	8.12	5.91	.13
2	2	-25	1358	1338	2.10	.015	59.2	.93	42.34	13.62	10.12	.42
2	2	-25	1308	1218	2.31	.069	56.9	.99	48.51	19.81	12.66	.59
2	2	-25	1360	1263	2.30	.071	57.6	1.00	53.51	24.84	10.93	.81
2	2	-12	1521	1521	1.71	.000	57.1	.91	18.71	5.20	4.62	.04
2	2	-12	1531	1471	1.77	.039	56.7	.94	34.49	11.20	8.74	.32
2	2	-12	1559	1559	1.95	.000	70.3	.83	15.85	3.13	3.60	.01
2	2	-12	1631	1631	2.08	.000	70.4	.93	29.50	7.91	6.36	.12
2	2	-12	1572	1572	1.79	.000	70.3	.77	10.00	1.93	2.33	.00
2	2	-12	1499	1499	1.70	.000	70.4	.68	11.51	2.04	2.76	.01
2	2	0	1804	1800	2.03	.002	75.6	.91	22.36	5.54	5.40	.08
2	2	0	1754	1750	2.07	.002	75.7	.90	32.44	7.45	7.91	.16
2	2	0	1806	1766	2.25	.022	75.4	.99	42.94	13.30	9.44	.35
2	2	0	1766	1722	2.33	.025	75.8	.99	41.25	17.99	9.27	.61
2	2	0	1769	1769	1.78	.000	70.6	.85	14.42	2.97	3.47	.01
2	2	0	1737	1737	1.81	.000	70.5	.86	17.76	3.69	3.95	.02
2	2	0	1769	1769	2.26	.000	81.2	.92	25.15	5.30	5.79	.08
2	2	0	1737	1737	2.30	.000	81.1	.93	27.79	7.31	6.61	.13
2	2	12	1898	1898	1.72	.000	75.2	.82	16.87	3.02	4.06	.02
2	2	12	1967	1967	1.67	.000	75.1	.83	13.02	2.83	2.96	.00
2	2	12	1928	1928	2.24	.000	81.8	.99	29.30	10.93	6.70	.25
2	2	12	2036	2010	2.19	.013	83.0	.99	36.58	15.64	8.57	.52
2	2	12	2007	1848	2.04	.079	71.7	1.00	48.01	19.37	10.32	.64
2	2	12	1966	1813	2.10	.078	72.4	1.00	42.04	19.32	9.03	.69
2	2	12	1991	1991	1.74	.000	70.3	.99	20.61	4.33	4.34	.03

2	2	12	1976	1976	1.69	.000	70.7	.92	21.60	5.43	4.85	.05
2	2	25	2141	2141	1.71	.000	75.2	.93	19.26	5.43	4.59	.04
2	2	25	2167	2167	1.69	.000	75.1	.93	21.33	6.55	5.10	.07
2	2	25	2180	2106	1.70	.034	70.6	.98	34.07	14.51	8.05	.46
2	2	25	2220	2176	1.68	.020	71.7	.99	32.34	11.01	7.61	.26
2	2	25	2242	2107	2.06	.060	82.2	1.00	42.08	18.93	7.94	.68
2	2	25	2199	2113	2.06	.039	82.3	.99	37.00	15.08	8.30	.47
2	2	25	2167	2167	2.06	.000	89.0	.94	30.92	9.03	7.59	.22
2	2	25	2218	2218	2.04	.000	88.9	.94	27.61	8.51	7.29	.20
2	2	45	2552	2491	1.70	.024	81.5	.98	34.82	10.32	8.15	.25
2	2	45	2568	2460	1.75	.042	81.9	.99	40.70	14.93	9.18	.45
2	2	45	2550	2499	1.74	.020	88.2	.91	28.29	7.55	7.67	.21
2	2	45	2588	2505	1.77	.032	88.1	.94	31.97	9.84	7.83	.23

```

;
proc reg;
  model max = chrs qxck qxchrs custxck;
  model wait = ckout chrs custxck;
  model chrs = custxck custxwt;
  model chrs = custlgck custxwt;
run;

```

REGRESSION ANALYSIS - OUTPUT

Dependent Variable: MAX

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	15684.33559	3921.08390	82.605	0.0001
Error	143	6787.88089	47.46770		
C Total	147	22472.21648			
Root MSE					
		6.88968	R-square	0.6979	
Dep Mean					
		24.96331	Adj R-sq	0.6895	
C.V.					
		27.59923			

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	26.998019	2.53796310	10.638	0.0001
CHRS	1	-1.164434	0.07601125	-15.319	0.0001
QXCK	1	7.082697	1.19492899	5.927	0.0001
QXCHRS	1	-0.087953	0.02739952	-3.210	0.0016
CUSTXCK	1	0.020454	0.00130765	15.642	0.0001

Dependent Variable: WAIT

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	4581.01988	1527.00663	100.352	0.0001
Error	144	2191.17351	15.21648		
C Total	147	6772.19339			
Root MSE					
		3.90083	R-square	0.6764	
Dep Mean					
		9.63797	Adj R-sq	0.6697	
C.V.					
		40.47356			

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	10.867185	1.55965027	6.968	0.0001
CKOUT	1	6.160415	1.13890428	5.409	0.0001
CHRS	1	-0.778522	0.04614288	-16.872	0.0001
CUSTXCK	1	0.012381	0.00073562	16.831	0.0001

Dependent Variable: CHRS

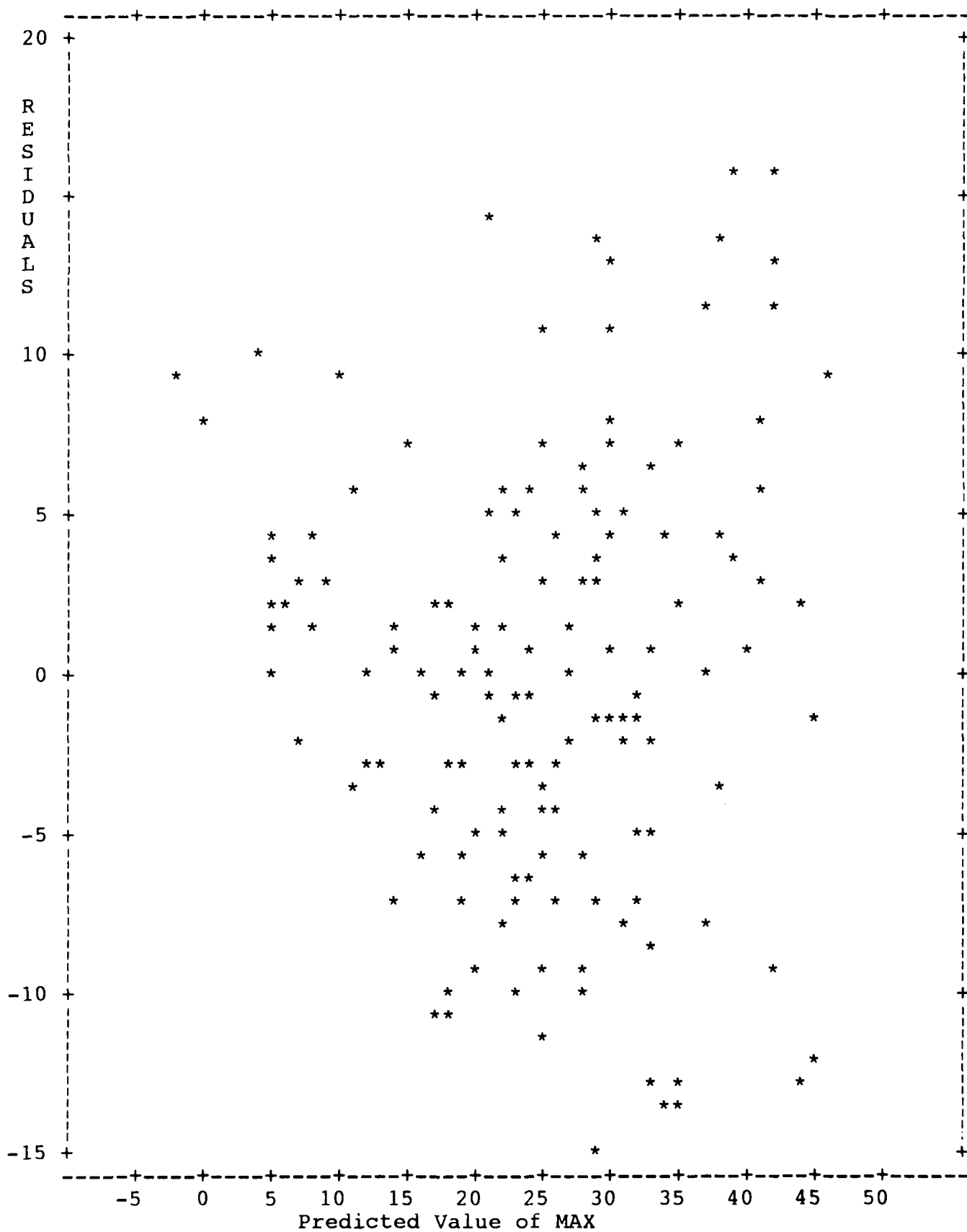
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	276413.82473	138206.91236	6943.08	0.0001
Error	145	2886.32446	19.90569		
C Total	147	279300.14919			
Root MSE					
		4.46158	R-square	0.9897	
Dep Mean					
		110.77027	Adj R-sq	0.9895	
C.V.					
		4.02778			

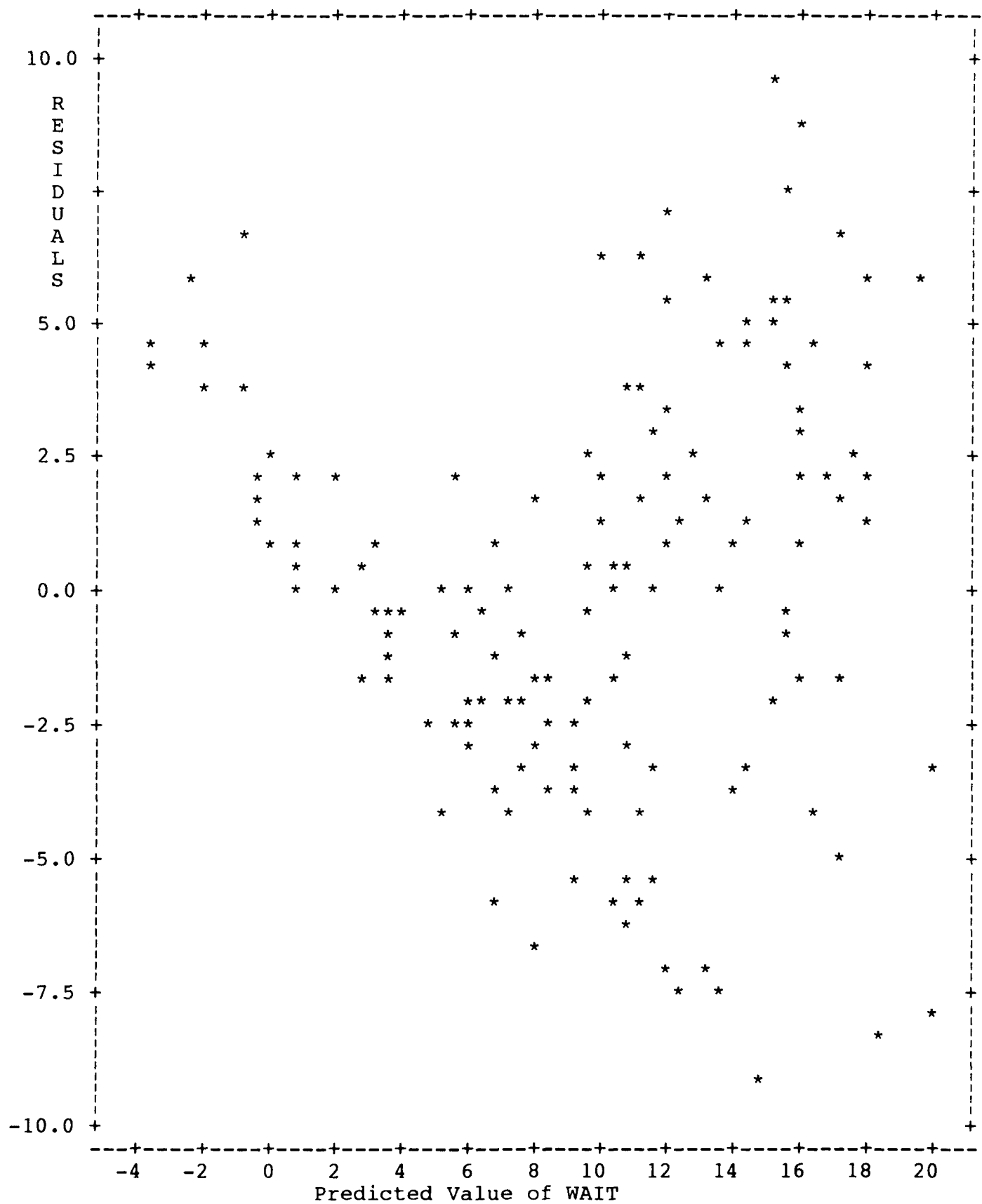
Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	16.252728	0.89941456	18.070	0.0001
CUSTXCK	1	0.018303	0.00016655	109.894	0.0001
CUSTXWT	1	-0.000396	0.00002384	-16.616	0.0001

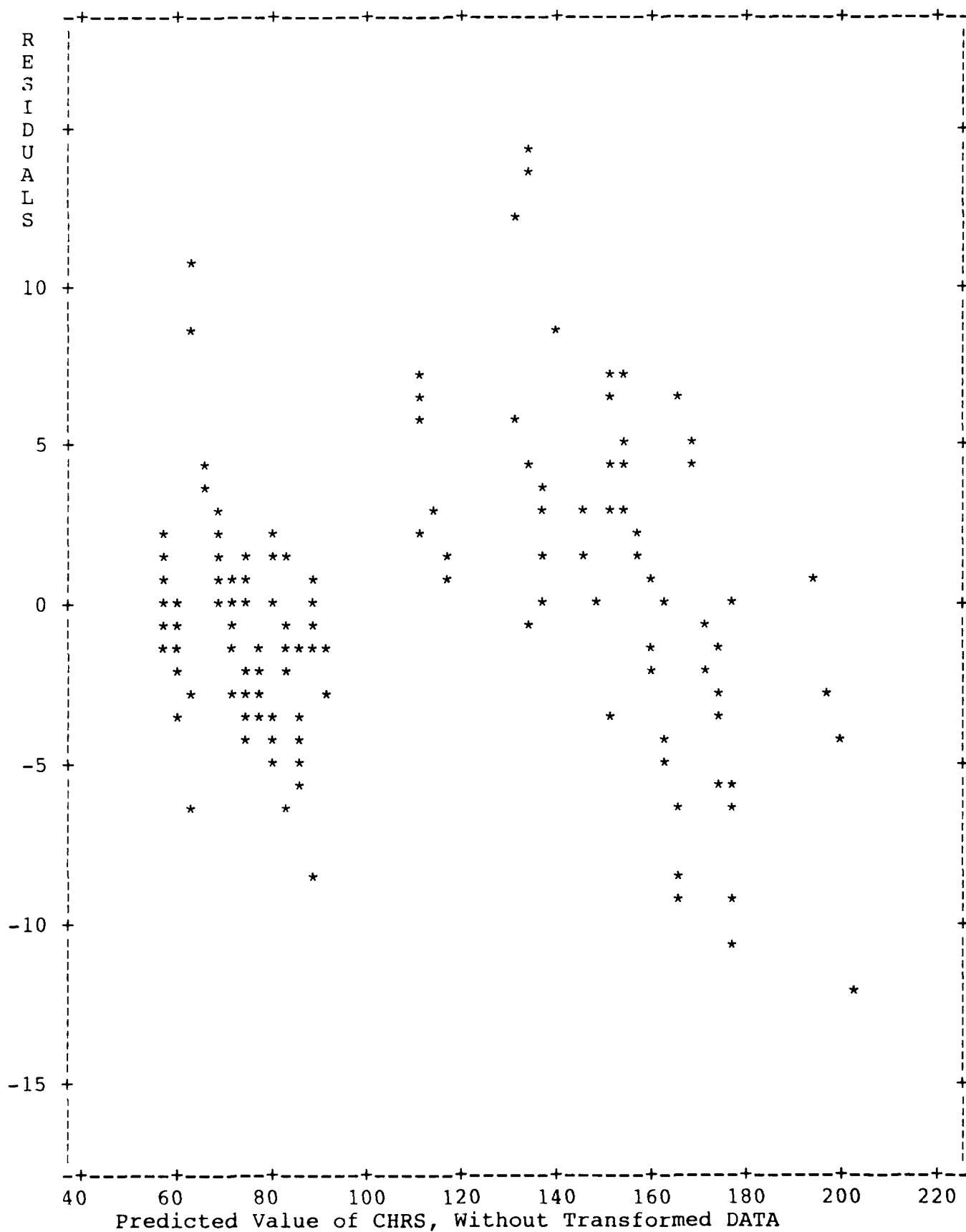
Dependent Variable: CHRS

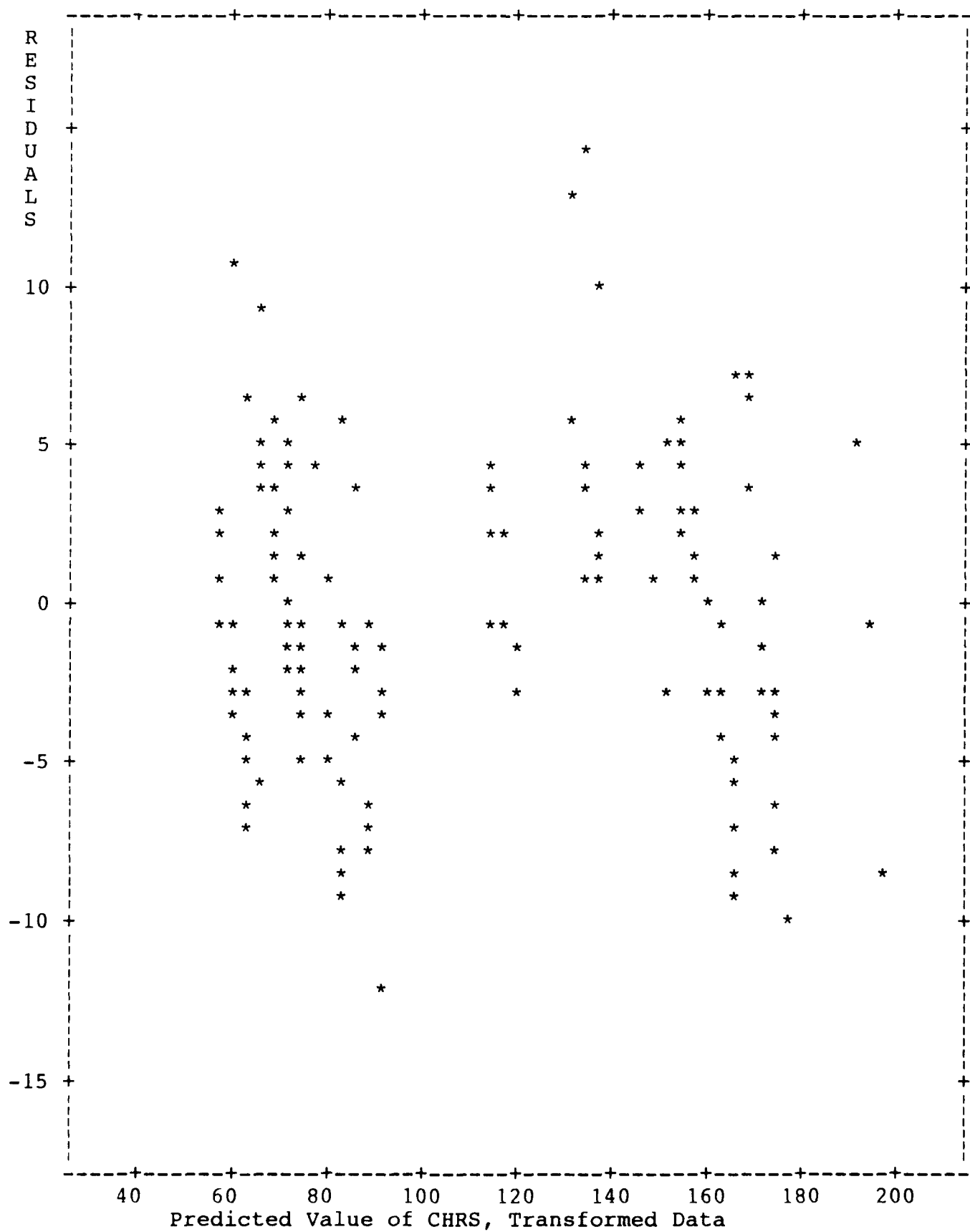
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	275752.12371	137876.06185	5634.691	0.0001
Error	145	3548.02548	24.46914		
C Total	147	279300.14919			
Root MSE					
		4.94663	R-square	0.9873	
Dep Mean					
		110.77027	Adj R-sq	0.9871	
C.V.					
		4.46567			

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	23.007552	0.94707263	24.293	0.0001
CUSTLGCK	1	0.047743	0.00048234	98.982	0.0001
CUSTXWT	1	-0.000359	0.00002625	-13.655	0.0001









APPENDIX D. Computer Code/Output

Computer Code to Generate Tables of Cashier Hours Vs. Customers, Service Time.....	128
Output, Cashier Hours Table.....	129
Code for Calculation of Monthly Cashier Hours.....	130
Output - Esimated Cashier Hours for Lackland AFB	
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Output - Esimated Cashier Hours for Rhein Main AB	
Month of Functional Review, 6 Minute Wait.....	133
Month of Functional Review, 15 Minute Wait.....	133

**Computer Code to Generate Tables of
Cashier Hours Vs. Customers, Service Time**

```

PROGRAM MAIN
real chrs(7)
integer nc(7)
data nclow,nchigh,nintvl/1200,3000,300/
data cklow/1.75/
do 2 i=1,7
2   nc(i)=nclow+(i-1)*nintvl
   do 5 iwait=4,12,4
   wait=iwait
   write(3,210)(nc(i),i=1,7)
210  format(9x,7(4x,i4))
   do 10 nckout=1,8
   i=0
   do 20 ncust=nclow,nchigh,nintvl
   i=i+1
   ckout=cklow+(nckout-1)*.25
   custwt=ncust*wait
   custlck=ncust*log(ckout)
   chrs(i)=23.0075+0.047743*custlck-0.000359*custwt
20  continue
   write(3,100) ckout,(chrs(i),i=1,7)
100  format(5x,f4.2,7(3x,f5.1))
10  continue
   write(3,200)wait
200  format(10x/, ' Average customer waiting time = ',f4.1/)
5    continue
stop
end

```

Output for Tables

	1200	1500	1800	2100	2400	2700	3000
1.75	53.3	60.9	68.5	76.1	83.7	91.3	98.9
2.00	61.0	70.5	80.0	89.5	99.0	108.5	118.0
2.25	67.7	78.9	90.1	101.3	112.5	123.7	134.8
2.50	73.8	86.5	99.2	111.9	124.6	137.2	149.9
2.75	79.2	93.3	107.4	121.4	135.5	149.5	163.6
3.00	84.2	99.5	114.8	130.1	145.4	160.7	176.1
3.25	88.8	105.3	121.7	138.2	154.6	171.1	187.5
3.50	93.1	110.6	128.1	145.6	163.1	180.6	198.1

Average customer waiting time = 4.0

	1200	1500	1800	2100	2400	2700	3000
1.75	51.6	58.8	65.9	73.1	80.2	87.4	94.5
2.00	59.3	68.3	77.4	86.5	95.5	104.6	113.7
2.25	66.0	76.8	87.5	98.3	109.0	119.8	130.5
2.50	72.1	84.3	96.6	108.8	121.1	133.4	145.6
2.75	77.5	91.1	104.8	118.4	132.0	145.7	159.3
3.00	82.5	97.4	112.2	127.1	142.0	156.9	171.7
3.25	87.1	103.1	119.1	135.1	151.2	167.2	183.2
3.50	91.3	108.4	125.5	142.6	159.7	176.7	193.8

Average customer waiting time = 8.0

	1200	1500	1800	2100	2400	2700	3000
1.75	49.9	56.6	63.3	70.1	76.8	83.5	90.2
2.00	57.5	66.2	74.8	83.5	92.1	100.7	109.4
2.25	64.3	74.6	84.9	95.3	105.6	115.9	126.2
2.50	70.3	82.2	94.0	105.8	117.7	129.5	141.3
2.75	75.8	89.0	102.2	115.4	128.6	141.8	155.0
3.00	80.8	95.2	109.7	124.1	138.6	153.0	167.4
3.25	85.4	101.0	116.5	132.1	147.7	163.3	178.9
3.50	89.6	106.3	122.9	139.6	156.2	172.9	189.5

Average customer waiting time = 12.0

Computer Program to Calculate Cashier Hours

```

PROGRAM MAIN
  real rn1(25),rn2(25),rn3(25),mckout,mwait
*** input for mean customers, checkout time, waiting time
  data mcust,mckout,mwait,nday/2534,3.04,6.0,25/
*** random numbers from 'Discrete Event Simulation', Banks & Carson
  data rn1/94737,87259,63856,66612,30712,69607,37792,01488,66248
1,51453,92168,36463,47097,80400,94554,31567,07821,09056,19922
1,29923,29602,94135,87926,85039,66070/
  data rn2/08225,85982,14016,54714,58582,24145,27282,56680,97697
1,03462,82530,07331,78780,45972,13863,53597,24759,10709,37025
1,02570,29464,94661,34092,19212,38480/
  data rn3/35614,13296,18527,46783,05704,43886,94107,73847,38244
1,61157,19271,54590,04210,44111,88239,08490,47266,69314,80731
1,80164,99219,87724,34334,59160,74636/
*** convert random number to range (0.0,1.0)
  do 5 i=1,nday
    rn1(i)=rn1(i)/100000.0
    rn2(i)=rn2(i)/100000.0
    rn3(i)=rn3(i)/100000.0
    if(rn1(i).gt.1.0) write(3,*) 'error in rn1'
    if(rn2(i).gt.1.0) write(3,*) 'error in rn2'
    if(rn3(i).gt.1.0) write(3,*) 'error in rn3'
  5 continue
*** write identifying information
  write(3,130)mcust,mckout,mwait,nday
130 format(/,' Based on:',5x,i4,' Average Customers/Day',/,15x,f4.2
1,' Average Service Time/Transaction',/,15x,f4.1,' Average Wait'/
1,15x,i4,' Days Open'/)
*** set accumulation variables to 0
  tothrs=0.0
  ntcust=0
  tckout=0.0
  twait=0.0
*** transformation: unfrm(a,b) --> a+(b-a)*rn
*   customers: 30% above/below mean
*   service time: 15% above/below mean
*   average wait: 50% above/below mean
  do 10 i=1,nday
    ncust=(0.7+0.6*rn1(i))*mcust
    ckout=(0.85+0.30*rn2(i))*mckout
    wait=(0.5+1.0*rn3(i))*mwait
    custwt=ncust*wait
    custlck=ncust*log(ckout)
    chrs= 23.0075 + 0.047743*custlck - 0.000359*custwt
    write(3,100)i,ncust,ckout,wait,chrs
    ntcust=ntcust+ncust
    tothrs=tothrs+chrs
    tckout=tckout+ckout
    twait=twait+wait
  10 continue

```

```

10    continue
*** write output for each day
100  format(4x,i2,4x,i4,4x,f5.3,4x,f4.1,4x,f6.1)
      write(3,110)ntcust,tothrs
110  format('/Total',4x,i5,20x,f7.1)
      ackout=tckout/nday
      await=twait/nday
      write(3,115)ackout,await
115  format('Average',11x,f5.3,4x,f4.1)
      stop
      end

```

**Output - Cashier Hours for Lackland
Month of Functional Review
6 Minute Average Wait**

Based on: 2593 Average Customers/Day
3.04 Average Service Time/Transaction
6.0 Average Wait
25 Days Open

1	3289	2.659	5.1	163.8
2	3172	3.368	3.8	195.8
3	2808	2.712	4.1	145.9
4	2851	3.083	5.8	163.6
5	2292	3.118	3.3	138.0
6	2898	2.804	5.6	153.1
7	2403	2.833	8.6	128.3
8	1838	3.101	7.4	110.7
9	2845	3.475	5.3	180.0
10	2615	2.616	6.7	130.0
11	3249	3.337	4.2	198.3
12	2382	2.651	6.3	121.8
13	2547	3.302	3.3	158.6
14	3065	3.003	5.6	171.0
15	3286	2.710	8.3	162.9
16	2306	3.073	3.5	136.9
17	1936	2.810	5.8	107.7
18	1955	2.682	7.2	103.3
19	2125	2.922	7.8	119.0
20	2280	2.607	7.8	114.2
21	2275	2.853	9.0	122.8
22	3279	3.447	8.3	200.3
23	3183	2.895	5.1	172.0
24	3138	2.759	6.5	160.9
25	2843	2.935	7.5	154.8

Total	66860			3713.4
Average		2.950	6.1	

**Output - Cashier Hours for Lackland
Month of Functional Review
15 Minute Average Wait**

Based on: 2593 Average Customers/Day
3.04 Average Service Time/Transaction
15.0 Average Wait
25 Days Open

Total	66860			3496.6
Average		2.950	15.2	

**Output - Cashier Hours for Rhein Main
Month of Functional Review
6 Minute Average Wait**

Based on: 1734 Average Customers/Day
2.02 Average Service Time/Transaction
6.0 Average Wait
21 Days Open

1	2199	1.767	5.1	72.0
2	2121	2.238	3.8	94.9
3	1878	1.802	4.1	66.3
4	1906	2.049	5.8	77.5
5	1533	2.072	3.3	67.7
6	1937	1.863	5.6	69.9
7	1606	1.882	8.6	59.8
8	1229	2.060	7.4	55.4
9	1903	2.309	5.3	88.7
10	1749	1.738	6.7	58.2
11	2172	2.217	4.2	95.6
12	1593	1.761	6.3	55.7
13	1703	2.194	3.3	78.2
14	2050	1.996	5.6	79.7
15	2197	1.801	8.3	71.4
16	1542	2.042	3.5	66.9
17	1295	1.867	5.8	52.1
18	1308	1.782	7.2	49.0
19	1421	1.941	7.8	57.3
20	1525	1.733	7.8	52.0
21	1521	1.896	9.0	57.8
Total	36388			1426.0
Average		1.953	5.9	

**Output - Cashier Hours for Rhein Main
Month of Functional Review
15 Minute Average Wait**

Based on: 1734 Average Customers/Day
2.02 Average Service Time/Transaction
15.0 Average Wait
21 Days Open

Total	36388			1311.7
Average		1.953	14.8	

APPENDIX E. Miscellaneous Analysis

Arrival Rate and Service Time Analysis

ANOVA and Regression Input	135
Regression Output	136
ANOVA Output.....	137
Plot, Arrival Rate Residuals.....	139
Plot, Service Time Residuals.....	140
Arrival Pattern Analysis.....	141

Arrival Rate and Service Time Analysis

The following is a quick analysis on arrival rate and service time data. The data set is too limited to do a thorough analysis, since the only holiday occurs on a payday, and all paydays occur on Friday. This analysis is shown as a demonstration of how this could be performed with a sufficiently large data set. The method for coding the day of the week is an example; other methods may prove more effective.

Day of the week was coded (1 for Wed, Thurs, Fri; 2 for Sun, Tues; and 3 for Sat) based on the rationale that Sat is busiest, Sun and Tues are slightly busier because the commissary is closed on Mon);

Payday includes the payday and the day after; and

Holiday includes the three days prior to the holiday.

DATA WAIT;

INPUT store day payday holiday cust ckout @@;

logday=log(day);

sxd = store*day;

sxpd = store*payday;

CARDS;

1	1	1	1	3008	2.67	2	1	1	1	1308	1.85
1	1	1	1	3142	3.21	2	1	1	1	1719	2.12
1	1	2	2	2191	3.34	2	1	2	1	1776	2.04
1	3	2	2	2992	3.55	2	3	2	1	2221	2.18
1	2	2	2	2044	3.12	2	2	1	1	1732	1.97
1	2	1	1	3081	3.10	2	1	1	1	1286	2.17
1	1	1	1	2168	2.83	2	1	1	1	1320	2.17
1	1	1	1	3001	3.04	2	1	1	1	1332	2.00
1	1	1	1	2590	2.84	2	3	1	1	2086	1.75
1	3	1	1	2743	3.07	2	2	1	1	1707	1.77
1	2	1	1	1942	2.70	2	1	1	1	1761	2.21
1	2	1	1	2899	2.63	2	1	2	1	1789	2.27
1	1	1	1	2168	2.80	2	3	2	1	2531	2.00
1	1	2	1	2558	2.88	2	2	1	1	1732	1.79
1	1	2	1	2563	2.95	2	1	1	1	1710	1.68
1	3	2	1	2822	3.39	1	2	1	1	2672	3.26
1	2	1	1	2106	3.15						

;

```

PROC GLM;
  CLASS store day payday holday;
  MODEL cust ckout = store | day | payday holday @2;
RUN;
proc reg;
  model cust = store day logday;
  plot residual.*predicted.='*';
  model ckout = store day logday sxd payday holday;
  plot residual.*predicted.='*';
run;

```

General Linear Models Procedure

Class Level Information

Class	Levels	Values
-------	--------	--------

STORE	2	1 2
DAY	3	1 2 3
PAYDAY	2	1 2
HOLDAY	2	1 2

Number of observations in data set = 33

General Linear Models Procedure

Dependent Variable: CUST

Source	DF	Sum of Squares	F Value	Pr > F
Model	11	8091818.87446	6.50	0.0001
Error	21	2376006.09524		
Corrected Total	32	10467824.96970		

R-Square	C.V.	CUST Mean
0.773018	15.26840	2203.0303030

Source	DF	Type I SS	F Value	Pr > F
STORE	1	6049709.19192	53.47	0.0001
DAY	2	1187312.86458	5.25	0.0142
STORE*DAY	2	303878.02431	1.34	0.2826
PAYDAY	1	3490.79612	0.03	0.8623
STORE*PAYDAY	1	362445.95230	3.20	0.0879
DAY*PAYDAY	2	122528.49297	0.54	0.5898
STORE*DAY*PAYDAY	1	40143.45703	0.35	0.5578
HOLDAY	1	22310.09524	0.20	0.6615

General Linear Models Procedure

Dependent Variable: CKOUT

Source	DF	Sum of Squares	F Value	Pr > F
Model	11	9.54590788	21.85	0.0001
Error	21	0.83388000		
Corrected Total	32	10.37978788		

R-Square	C.V.	CKOUT Mean
0.919663	7.782146	2.56060606

Source	DF	Type I SS	F Value	Pr > F
STORE	1	8.70445343	219.21	0.0001
DAY	2	0.17742646	2.23	0.1319
STORE*DAY	2	0.27288576	3.44	0.0512
PAYDAY	1	0.22446602	5.65	0.0270
STORE*PAYDAY	1	0.00020755	0.01	0.9430
DAY*PAYDAY	2	0.05312574	0.67	0.5228
STORE*DAY*PAYDAY	1	0.00019053	0.00	0.9454
HOLDAY	1	0.11315238	2.85	0.1062

Model: MODEL1

Dependent Variable: CUST

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	7237022.0565	2412340.6855	21.653	0.0001
Error	29	3230802.9132	111406.99701		
C Total	32	10467824.970			

Root MSE	333.77687	R-square	0.6914
Dep Mean	2203.03030	Adj R-sq	0.6594
C.V.	15.15081		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	2175.451989	547.48241990	3.974	0.0004
STORE	1	-877.604167	118.00794306	-7.437	0.0001
DAY	1	1218.176483	553.39990378	2.201	0.0358
LOGDAY	1	-1772.911040	957.13947275	-1.852	0.0742

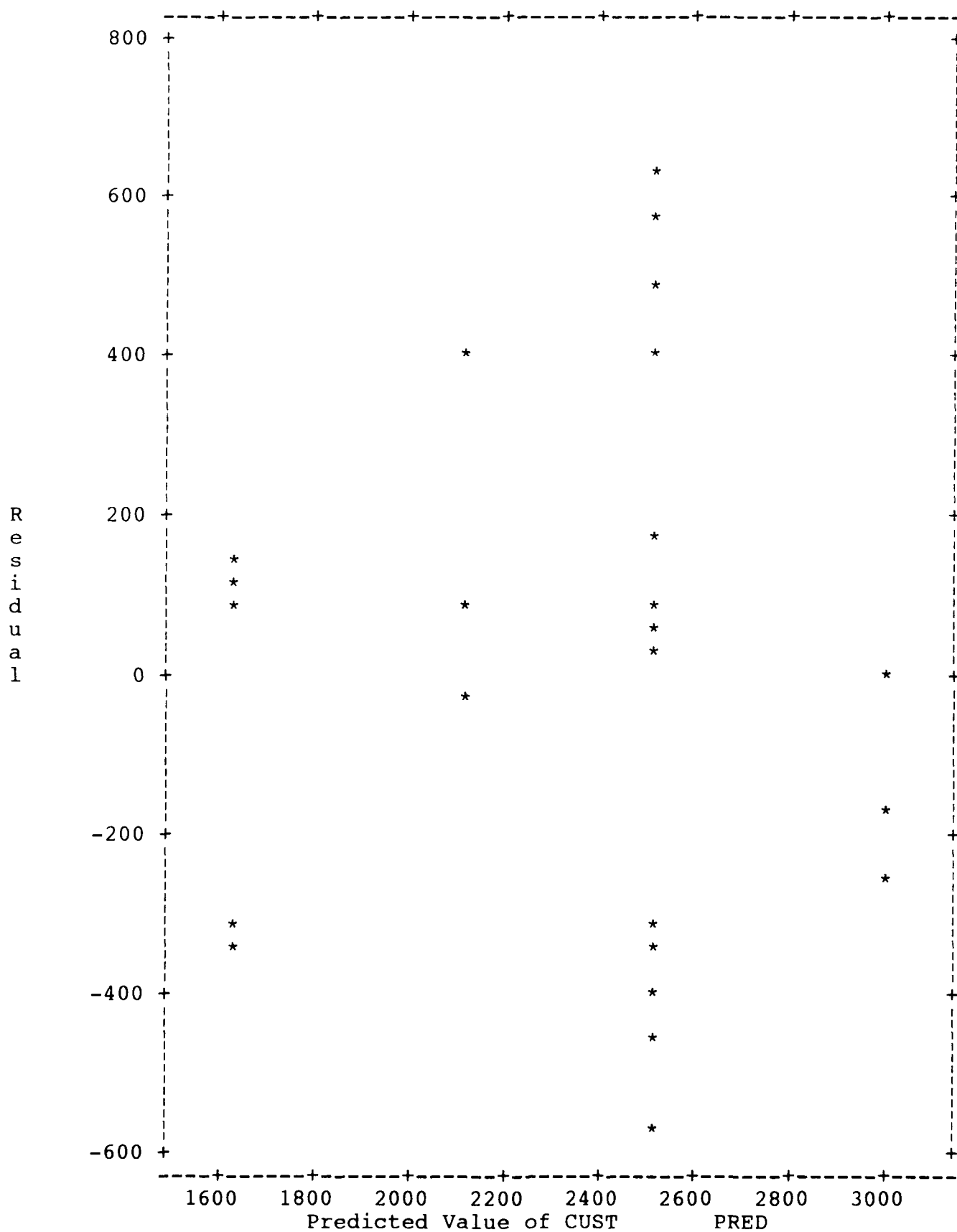
Model: MODEL2

Dependent Variable: CKOUT

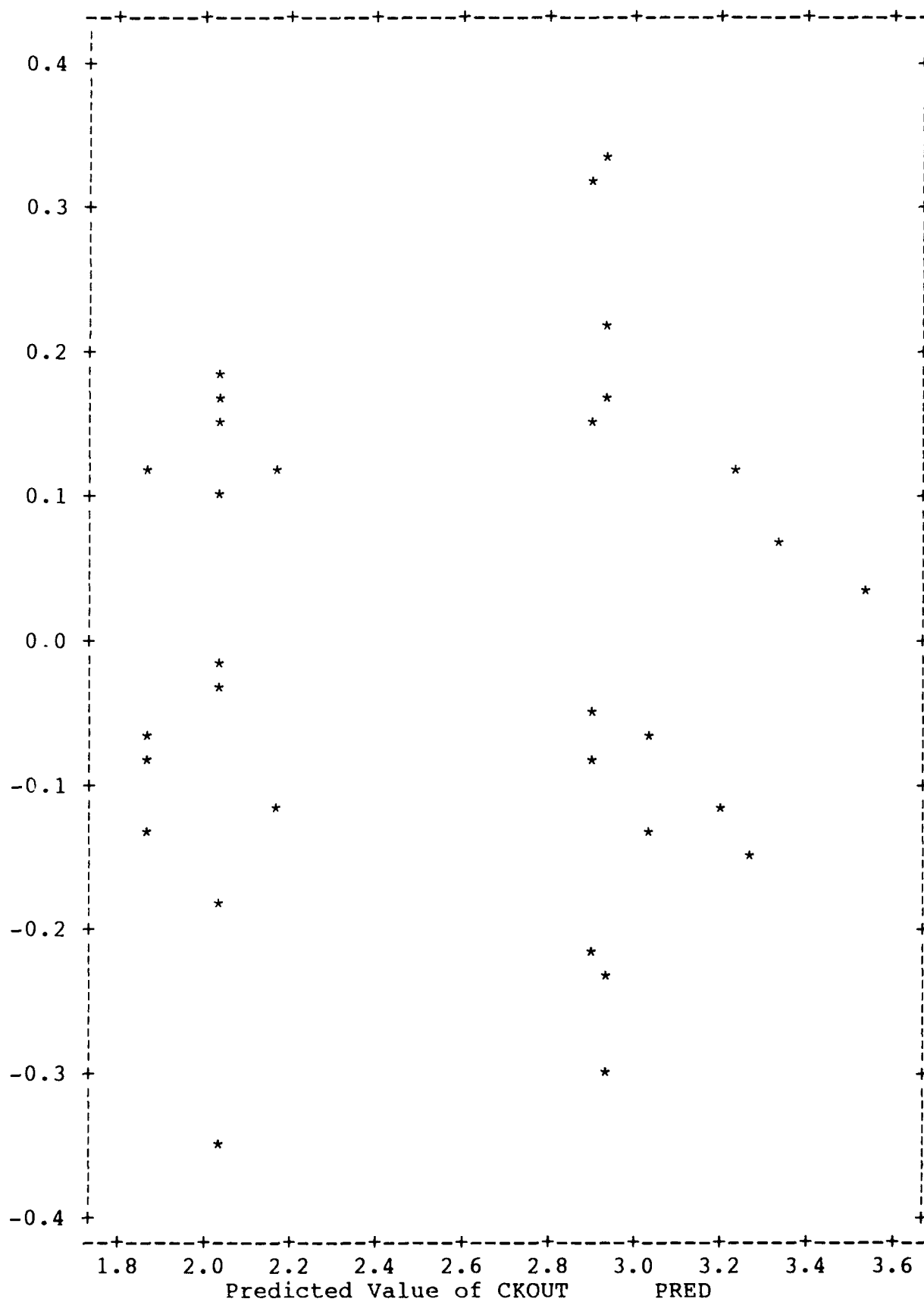
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	9.45299	1.57550	44.198	0.0001
Error	26	0.92680	0.03565		
C Total	32	10.37979			

Root MSE	0.18880	R-square	0.9107
Dep Mean	2.56061	Adj R-sq	0.8901
C.V.	7.37332		

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	2.649998	0.40538819	6.537	0.0001
STORE	1	-0.639342	0.15489273	-4.128	0.0003
DAY	1	0.759957	0.36873159	2.061	0.0494
LOGDAY	1	-0.709441	0.58641672	-1.210	0.2372
SXD	1	-0.220746	0.08706482	-2.535	0.0176
PAYDAY	1	0.133948	0.09054512	1.479	0.1511
HOLDAY	1	0.201704	0.14021970	1.438	0.1622



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Arrival Pattern Analysis

For the arrival pattern analysis, data from the Lackland commissary was used. The percentage of total daily customers arriving each hour was calculated. The mean and standard deviation was calculated for all days when the commissary was open 10 hours. (Sunday and Thursday would have a different pattern). The results are as follows:

Hour	\bar{x}	s	80% c.i.
1	5.51	1.54	4.2 - 6.9
2	9.30	1.57	7.9 - 10.7
3	10.94	1.26	9.8 - 12.0
4	11.07	0.97	10.2 - 11.9
5	11.21	1.23	10.1 - 12.3
6	11.75	1.04	10.8 - 12.7
7	12.33	1.25	11.2 - 13.4
8	12.31	1.21	11.3 - 13.4
9	11.23	1.91	9.6 - 12.9
10	4.75	1.78	3.2 - 6.3

Different arrival patterns could be identified and the simulation model run to determine what effect the pattern has on wait time and utilization. If the difference is significant, a method for predicting the arrival pattern based on day of the week, payday, and holiday would be desirable.

APPENDIX F. AFCOMS Manpower Standard Input/Output

Workload Factor Inputs by Base	143
Output From MSDS Manpower Statistical Analysis	144

COMPREHENSIVE DATA FILE USED IN DEVELOPMENT
OF AFCOMS MANPOWER STANDARD FOR CUSTOMER SERVICE

BASE	CHKR HRS	TOT SAL	CUSTRS	ITEMS	OP HRS	OP DAYS	COUP
CAMP FOSTER	3665.34	1766998	43345	1667510	250.01	30.44	36935
CARSWELL	5614.62	3930185	57743	3345334	226.01	25.26	288732
EGLIN	5153.37	2967750	61183	2535930	336.97	25.26	123312
FAIRCHILD	3846.73	1796936	33769	1634897	191.31	20.91	115430
GRISSOM	2239.92	761414	20690	663491	193.49	20.91	49174
HAHN	2013.95	786627	25738	1087050	191.31	20.91	25291
KELLY	1393.46	661640	19528	577399	186.96	20.91	37537
LACKLAND	5918.18	3616006	68235	3200895	234.79	25.26	222692
MACDILL	10892.68	4282829	72646	3964098	261.88	30.44	362946
MISAWA	2190.52	897196	32224	1040412	217.40	25.26	12950
RAF LAKENHTH	3488.17	1519453	38192	1416102	200.01	25.26	36625
RAMSTEIN	4943.80	2124462	60038	1969897	230.44	25.26	48934
RHEIN MAIN	2332.54	1358928	38044	1201717	191.31	20.91	30298
SHAW	2833.92	1281143	30834	1133560	210.88	20.91	66269
VANDENBERG	3072.87	1465377	35103	1333494	210.88	25.26	91919
WILLIAMS	3018.93	1470853	28860	1302103	210.88	25.26	136706

WLF ORDER OF ENTRY		I N T E R M E D I A T E R VALUES R2 VALUES	
(1)	WORKLOAD FACTOR 1	0.8760	0.7674
(3)	WORKLOAD FACTOR 3	0.9428	0.8890
(2)	WORKLOAD FACTOR 2	0.9511	0.9046

EQUATION & STATISTICS

A	R	R2	SY	V	F
-2485.8422	0.9511	0.9046	794.2970	0.2030	37.9330
WLF			B(I)	T(I)	CONF LEV
A CUSTOMER SERVED			0.05681714	2.870	0.985907
A STORE OPERATING DAY			118.32349150	1.403	0.814049
A MERCHANDISE COUPON PROCESSED			0.01103443	3.869	0.997769

EXTRAPOLATION LIMITS

Y-UPPER	Y-LOWER
11560.444	1134.018

BIBLIOGRAPHY

1. "Air Force Commissary Service." Air Force Magazine: 115 (May 1986).
2. Air Force Commissary Service Commander's Summary. Headquarters Air Force Commissary Service, Directorate of the Comptroller, Kelly AFB TX, March 1989.
3. Air Force Commissary Service Functional Review Study: Final Report. Headquarters Air Force Commissary Service, Directorate of Strategic Plans and Analysis, Functional Review Division, Kelly AFB TX, 31 July 1989.
4. Air Force Regulation 25-5, Volume I. Department of the Air Force, Headquarters US Air Force, Washington, D.C., 1 April 1982.
5. Baker, Kenneth R. "Workforce Allocation in Cyclical Scheduling Problems: A Survey," Operational Research Quarterly, 27: 155-167 (1976).
6. Banks, Jerry and John S. Carson, II. Discrete-Event System Simulation. Englewood Cliffs NJ: Prentice-Hall, 1984.
7. Britt Richard J. Optimization of Inventory Levels For the Air Force Commissary Service. MS Thesis, AFIT/GOR/ENS/88D-4. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, December 1988.
8. Cooper, Robert B. Introduction to Queueing Theory. New York: Macmillan, 1972.
9. Cox, D.R. and Walter L. Smith. Queues. London: Chapman and Hall Ltd, 1979.
10. Dorough, Robert E. and Robert E. Holliway. A Simulation Study of Checkout Operations at the Wright-Patterson AFB Commissary. MS Thesis, AFIT/LSSR/6-80. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, June 1980.
11. Foote, B. L. "A Queueing Case Study of Drive-In Banking," Interfaces, 6: 31-37 (August 1976).
12. Frey, Thomas J. Optimal Server Scheduling to Maintain Constant Customer Waiting Times. MS Thesis, AFIT/GOR/ENS/88D-7. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December, 1988.
13. Grassmann, W. K. "The Economic Service Rate," Journal of the Operational Research Society, 30: 149-155 (No. 2).

14. Gross, Donald and Carl M. Harris. Fundamentals of Queueing Theory. New York: John Wiley and Sons, 1974.
15. Gunst, Richard F. and Robert L. Mason. Regression Analysis and Its Application. New York: Marcel Dekker, 1980.
16. Hillier, Frederick S. and Gerald J. Lieberman. Introduction to Operations Research. (Fourth Edition). Oakland CA: Holden-Day 1986.
17. Jones, Kenneth. Personal Interview. HQ AFCONS, Kelly AFB TX, 10 Aug 89.
18. Jones, Michael T., Arlene M. O'Berski, and Gail Tom. "Quickening the Queue in Grocery Stores," Interfaces, 10: 90-92 (June 1980).
19. Juarez, Richard. Personal Interview. HQ AFCONS, Kelly AFB TX, 23 Oct 89.
20. Koelling, C. Patrick and James E. Bailey. "A Multiple Criteria Decision Aid for Personnel Scheduling," IIE Transactions, 16: 299-307 (December 1984).
21. Krajewski, L. J. and others. "Shift Scheduling in Banking Operations: A Case Application," Interfaces, 10: 1-8 (April 1980).
22. Kwan, Stephen K., Mark M. Davis, and Allen G. Greenwood. "A Simulation Model for Determining Variable Worker Requirements in a Service Operation with Time-Dependent Customer Demand," Queueing Systems, 3: 265-276 (1988).
23. Magazine, M. J. "Optimal Control of Multi-channel Service Systems," Naval Research Logistics Quarterly, 18: 177-183 (1971).
24. Montgomery, Douglas C. Design and Analysis of Experiments. (Second Edition). New York: John Wiley & Sons, 1984.
25. Morris, Michael F. and Paul F. Roth. Computer Performance Evaluation: Tools and Techniques For Effective Analysis. New York: Van Nostrand Reinhold Company, 1982.
26. Moulder, Roger D. Development of a General Purpose Commissary Store Simulation Model. MS Thesis, AFIT/GOR/ENS/87D-11. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December, 1987.
27. Naylor, T. H. and J. M. Finger. "Verification of Computer Simulation Models," Management Sciences, 14: 92-101 (1967).
28. Paul, R. J. and R. E. Stevens. "Staffing Service Activities with Waiting Line Models," Decision Sciences, 2: 206-218 (April 1980).

29. Pritsker, A. Alan B. Introduction to Simulation and SLAM. (Second Edition). West Lafayette IN: Systems Publishing, 1984.
30. Polk, Stanley B. Personal Interview. HQ AFCCOMS, Kelly AFB TX, 10 August 89.
31. Saaty, Thomas L. Elements of Queueing Theory With Applications. New York: Dover Publications, 1983.
32. Schlotzhauer, Sandra D. and Ramon C. Littell. SAS System for Elementary Statistical Analysis. Cary, NC: SAS Institute, 1987.
33. Stark, Michael B. A Comparison of the Performance of Three Inventory Control Strategies in the Commissary Store Environment. MS Thesis, AFIT/ENS/GOR/87D-20. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December, 1987.
34. Tabachnick, Barbara B. and Linda S. Fidell. Using Multivariate Statistics. New York: Harper & Row, 1983.
35. Weisselberg, Robert C. and Joseph G. Cowley. "Quickening the Queue," Journal of Systems Management, 20: 30-35 (October 1969).
36. Whitt, Ward. "Deciding Which Queue to Join: Some Counterexamples," Operations Research, 34: 55-62 (January-February 1986).

VITA

Captain Bruce Hamilton Fritz II was born on 31 January 1958 in Rockford, Illinois. He graduated from high school in Rockford in June of 1976 and entered the United States Air Force Academy that same month. He graduated from the Academy on 28 May 1980 with a Bachelor of Science Degree in Mathematics and was commissioned a Second Lieutenant in the United States Air Force. In January of 1981, he was assigned to the 544TH Strategic Intelligence Wing at Offutt AFB, Nebraska where he worked in the Trajectory Division of the Strategic Targeting Intelligence Center as a Ballistic Missile Trajectory Engineer. He entered the Air Force Institute of Technology in May of 1983. His following tour was with the Air Force Operational Test and Evaluation Center (AFOTEC) at Kirtland AFB, NM and began in January of 1985. There he was assigned to the Modeling and Simulation Division of the Directorate of Operations Analysis as a Weapon Systems Simulation Analyst until June of 1989. He then moved to the Air Force Commissary Service (AFCOMS) at Kelly AFB, TX where he was assigned as the Deputy Division Chief of the Analysis Division within the Directorate of Strategic Plans and Analysis until March of 1991. He then moved across town to Human Systems Division at Brooks AFB where he is currently assigned as a Systems Analyst in the Directorate of Mission Analysis under the Deputy Commander for Program Integration and Planning.

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